GREAT LAKES COASTAL RESEARCH LABORATORY
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AN EVALUATION OF PHYSICAL AND BIOLOGICAL CONTROLS ON COASTAL EROSION IN THE INDIANA DUNES NATIONAL LAKESHORE

Stephen E. Davis, William L. Wood, and Susan M. Markley

Final Report

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INTRODUCTION

When the National Park Service published it's master plan for development of the Indiana Dunes National Lakeshore, in 1969, they recommended that the area along the northeastern extremity of the Lakeshore be maintained as an interpretation and natural study area. This area, which includes the existing Michigan City West Beach and Mt. Baldy, was planned to have limited use dependent upon dune and beach stability. It was, therefore, the intent of National Park Service that any alteration or construction within this area adhere to the philosophy of maintaining the natural environmental conditions.

During the recent period of high water level on Lake Michigan the entire northeastern shoreline of Indiana has been subjected to excessive erosion. In areas where high dunes and bluffs exist, erosion has been accentuated by undercutting and slumping. The region upon which this study focuses is comprised of high dunes and bluffs and is classified, therefore, as a critical erosion area. The presence of the Michigan City breakwater complex immediately to the east of the study region presents an additional environmental pressure on the already critical shoreline erosion.

As a result of the critical erosion condition which exists in the study region numerous erosion control plans have been proposed to mitigate the situation. These plans range from constructional alternatives, designed to "wall off" the entire beach frontage from the lake, to the placement of natural sand nourishment on

the beach, with the intent of balancing ongoing beach erosion rates. This latter alternative has already been utilized in the study region as an interim protection measure for the dunes and for the privately owned homes within the Lakeshore jurisdiction.

The National Park Service is, therefore, concerned with long term planning for the Lakeshore coastline. This report presents an overview of the coastal environmental conditions which exist along the northeastern extremity of the Indiana Dunes National Lakeshore. It is intended to provide an evaluation of the effectiveness of the beach nourishment project in the Mt. Baldy region and to make recommendations for the best alternatives for the National Park Service to pursue in future planning and management decisions relating to this coastal area.

The four primary objectives of this investigation were:

1. To assess the long and short term coastal erosion within the study area.

2. To determine the coastal vegetative distribution and its influence on beach and dune stabilization.

3. To evaluate the effectiveness of beach nourishment as an alternative for controlling beach erosion and maintaining dune protection.

4. To recommend the best alternatives for beach erosion control and dune protection.

In order to meet these objectives an extensive research investigation was carried out utilizing field observational data and existing documentation from the study area. Vegetative map,

terrestrial and aerial photography, hydrographic and dune survey, and lake level data were used to complete the various phases of this study.

A major consideration in the preparation of this report was the recognition of the National Park Service's objective of maintaining a natural physical setting within the National Lakeshore coastal region. Therefore, the recommendations made in this report have been formulated to judiciously interface with this National Park Service goal.

PHYSICAL SETTING AND ENVIRONMENTAL CONDITIONS

Description of the Study Area

The study area, Figure 1, is bounded to the east by NIPSCO power plant facility, to the west by Montana Drive, to the south by Beverly Drive, and to the north by Lake Michigan. The shoreline in the study area is characterized by a narrow beach, fronting at the base of a recent wave cut bluff. This bluff extends from the NIPSCO breakwater westward along the lakefront to a rubble mound revetment constructed in front of the Beverly Shores residential area.

Although the bluff continues westward behind the revetment, it is at this time protected. Thus the western boundary of the study area was set at the end of the revetment structure.

The youngest dunes in the region range from a few feet to over one hundred and twenty feet above the present lake level. They extend back from the shore to the southern boundary of the study area, at Beverly Drive. The dune morphology is complex and reflects the interaction of erosional and depositional forces in the area.

The two mile section of beach along the northern boundary of the study area is continuous with the exception of Kintzele's Ditch (see Figure 1). This stream occurs approximately midway within the study area and serves as the major drainage outlet for water trapped in the marsh areas behind the dunes. The flow from

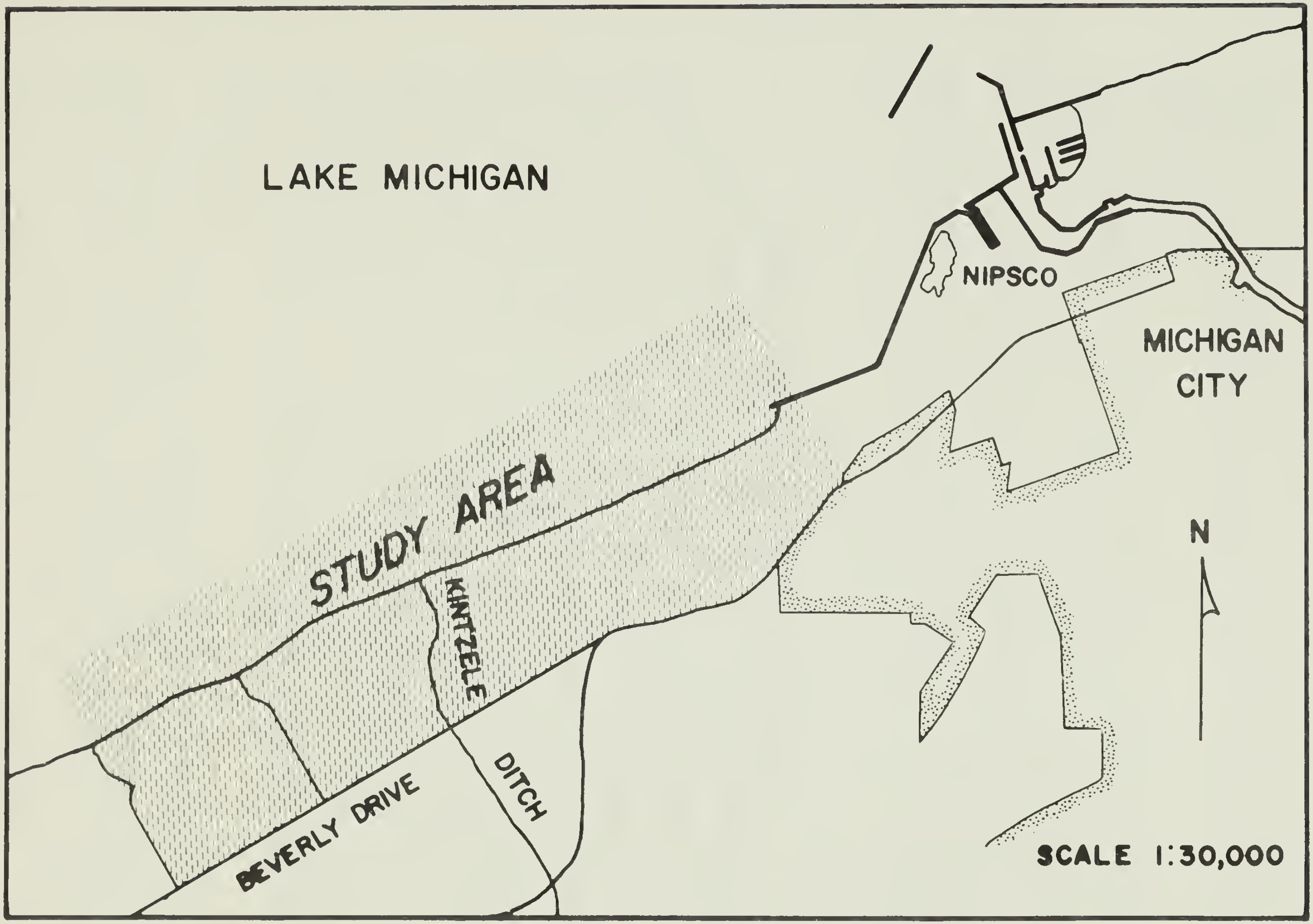

LAKE MICHIGAN
NIPSCO
MICHIGAN CITY
STUDY AREA
KINTZELE
DITCH
BEVERLY DRIVE
N
SCALE 1:30,000

FIGURE 1

Kintzele's Ditch is highly seasonal and during its maximum discharge periods the nearshore sediment balance is disrupted significantly.

The vegetation within the study region consists of a wide variety of plant species. The interaction of the vegetation with the various physical and geological conditions in the area results in numerous complex interrelationships. These interrelationships will be discussed extensively in section five of this report.

Geologic and Sedimentologic Characteristics

The Wisconsin glacier, being the last major Pleistocene glaciation in the study area, was responsible for most of the present day land forms and drainage patterns in the southern Lake Michigan region. As the glacier alternately retreated and readvanced, it would halt for periods of years depositing moraines of glacial outwash and scour material. One of the positions at which the edge of the ice sheet halted was the region known as the Valparaiso Moraine. This moraine extends from Wisconsin through the Fox Lake region of Illinois and then follows the contour of Lake Michigan through Indiana and on into Michigan.

The southern end of Lake Michigan began to form approximately 12,000 years ago during the Glenwood stage. At this stage the ice sheet was halted a short distance south of the present Lake Michigan basin. The ice provided a dam to the north which, when coupled with the higher land to the south and east, formed a reservoir

(known as Ancient Lake Chicago) for the large volumes of melt water coming from the glacier. Dunes began to form along the southern and eastern shores of Lake Chicago and are today called the Glenwood Dunes. The lake level was approximately 55-60 feet higher than present. Approximately 10,000 years ago (Calumet stage) the ice sheet retreated into the Lake Michigan basin, enlarging Lake Chicago and forming the Calumet Dunes. Lake level was now only about 35-40 feet above present level due to the continued drainage off to the southwest. The lake level continued to drop and then rose about 20 feet forming a new beach. This beach region cut off the Calumet Dunes from the lake, thus creating a lagoon between the dunes of this Tolleston beach and the older Calumet Dunes. The lake levels dropped, during the Champlain stage, about 60 feet below present level and created new beaches and cliffs. Shortly after this, during the Algonquin stage, the lake level rose about 15 feet above present and then lowered to present day levels. The zone of recent dunes, which make up the study area, are 2000 to 3000 years old.

The southern end of Lake Michigan is composed of the Wadsworth Till, the oldest known till in the region, which is either exposed on the lake bottom or is overlain by recent sediments. The surface and subsurface material in the study area and immediately offshore from it is a complex assemblage of till, reworked till, outwash sands and gravels, and lacustrine clays.

The nearshore and beach sediments are primarily reworked till which has been well sorted by continuous wave and current action. Thus, the principal sediment can be characterized as a well sorted medium sand. Coarse sand and some cobble exist at the beach step and in isolated areas offshore. The medium sand (1.5 to 2.0 ϕ) is found on the beach and in the shallow surf zone, while the finer sand (2.0 to 2.5 ϕ) grades gradually offshore. These characteristics are similar to those found by Davis and McGeary (1965) and Hawley and Judge (1969) for the southern Lake Michigan region. The primary sediment contrast is in the offshore region (in a depth of approximately -25 feet low water datum) where clay appears abundantly in certain areas. These observations of clay are unique in the southern Lake Michigan region and should be studied in more detail.

Wind and Wave Conditions

There is very little appropriate data available on wind conditions in the study area and virtually no data on waves. The best wind data available is that collected at the Ogden Dunes, U.S. Weather Bureau Cooperative Station, between 1949 and 1967.

These data indicate that the prevailing monthly wind is from the south at an annual average speed of 11 knots. However, maximum recorded wind speeds for each month ranged from 44 to 74 knots blowing from the north, northwest, or west. The primary sustained storm periods are in early spring and late fall. Waves from these sustained

storms are the primary causes of erosion along the National Lakeshore shoreline.

Rudimentary wave hindcasts have been generated from wind data recorded at Ogden Dunes. However, there is no available verification of these data, and thus their usefulness is limited. Wave data currently being collected by the Coastal Engineering Research Center through their LEO program may soon provide the necessary data base for assessing wave conditions in the study region. However, there is little known about the wind and wave conditions in the study region beyond the cursory information presented here.

Lake Level Variations

The International Great Lakes Datum of 1955 established low water datum for Lake Michigan at 576.8 feet above mean water level in Gulf of St. Lawrence at Father Point, Quebec. Average monthly surface water levels for Lake Michigan have been recorded since 1860. During that period of time the extreme range of water level variation has been 6.5 feet, from a high of +5.14 feet in July, 1886 to a low of -1.45 feet in March, 1964. The seasonal variability of the lake level produces highest levels in the summer and lowest levels in the winter. The annual range of water level fluctuation is approximately one foot.

An extremely important consideration in appraising the current period of high erosion is that the lake level rise from March, 1964 to July, 1974 (5.7 feet) is the greatest continuous increase in Lake

Michigan history. Consequently, in the last decade, the coastal region has not had any periods of lake level stationarity or retreat during which natural stabilization and rebuilding could occur. Thus the buffering normally provided by broad beaches and small foredunes is absent, and the high bluffs stand exposed to the seasonal storm waves. Until a significant reversal in the current lake level trend occurs there is no possibility for the National Lakeshore coastline to stabilize naturally.

The periodicity of lake level cycling is not a well understood phenomena with the obvious exception of the annual climatic fluctuation. A spectral analysis of the 110 year lake level record for Lake Michigan indicated significant periods of 4.2, 7.4, 12.2, and 22 years. There are no clear relationships between these periods and temporal variability in natural environmental phenomena. However, some of these periods must correspond to long term climatic variability and may be related to maritime-continental air mass balance. Unfortunately, the discernable periodicities do not provide a basis for predicting when lake surface levels will rise or fall because cause and effect relationships have not been established. What can be predicted, however, is how the coastal region will respond to the lake level variations. This response is discussed in detail in the two succeeding sections.

BEACH AND DUNE STABILITY

Introduction

The purpose of this section is to establish a set of conditions and to clarify the recession-erosion relationships for appraising beach and dune stability. The early parts of this section present a discussion of general characteristics and properties of beaches and dunes as they relate to their formation and stabilization. Intrinsic to this discussion is the consideration of natural development and natural stability of both beaches and dunes.

The latter parts of this section present a discussion of beach and dune recession and erosion rates along the study area coastline. Included in this discussion is a thorough evaluation of the difference between beach or dune recession and erosion.

Clarification of this difference between recession and erosion is extremely critical to understanding the evaluation of the effectiveness of beach nourishment and the recommendations for beach erosion control and dune protection, presented later in this report.

Physical Characteristics of the IDNLS Beach and Dunes

The coastline of the National Lakeshore consists of a barred tideless beach backed by a vegetatively controlled irregular dune system. There are two well defined offshore bars in this region. The outermost bar (in approximately -10 feet LWD) is relatively

stable and is influenced only by severe fall and spring storms. The inner bar (in approximately -2 feet LWD) adjusts itself continually to the variable intensity and concentration of breaking wave energy. Ephemeral bars occur, at irregular intervals, between the inner bar and the shore. These ephemeral bars will migrate shoreward and attach themselves to the beach forming a typical ridge and runnel system. This process, which has been observed in the spring and early fall, will bring sand from the shallow water regions to the shore. The net sediment accumulation from this process is not of major significance, because these accretional forms are eroded by the storm waves in the late fall and early spring. Therefore, a cyclic onshore-offshore sand transport is present and is primarily restricted to the area between the outer bar and the shore. Longshore transport of sand is responsible for carrying sediment through this zone of cyclic onshore-offshore transport. As long as the net sediment transported out of any region, between the outer bar and the shore, is zero, beach erosion will be minimal. This condition, though trivial, established the relationship that longshore sediment transport should be constant at discrete sequential positions along the shore unless erosion or accretion is occurring within some finite section of the nearshore zone. Thus when structural barriers are introduced across this active zone, sediment transport continuity is no longer maintained and erosion must occur on the downdrift side. This is precisely the condition represented by the presence of the Michigan City

breakwater complex. This structure blocks essentially all of the longshore sediment transport into the study area.

The dunes adjacent to the coast are characteristic of coastal dunes in wetted regions. The shape of these dunes is controlled to a large degree by vegetation. As a result these dunes form pyramid-like structures which are irregular in both size and shape. Likewise, they tend to be smaller than dunes formed on arid coasts.

Blowouts are frequently observed amongst this type of coastal dune system. Although most of the blowouts occur from natural processes, there are areas where human disruption of the vegetation has created blowout structures. Blowouts tend to form as deep hollow parabolic dunes with sharp sand ridges which close off the sides and then join to form the downwind ridge of the dune. Thus an interspersed pattern of plant controlled dunes and blowouts (parabolic dunes) typifies the coastal dune system of the National Lakeshore.

Most of the dunes in the study region have been stabilized by vegetative cover. Mt. Baldy, however, is still an active dune migrating southeastward under the influence of the dominant north and northwest winds. The asymmetric profile of Mt. Baldy is characteristic of migrating sand dunes and reflects the dominant onshore winds. In order for Mt. Baldy to continue to grow, a readily available sand source is needed in the beach region. If this sand source diminishes, then the foreslope is not replenished. Thus the dune

no longer grows, but begins to migrate as the foreslope sand is carried over the dune top and deposited on the lee slope. Unless the migrating dune encounters a substantial barrier it will continue to move as an active dune. A totally active dune of this type rarely becomes colonized by vegetation until both low wind energy and favorable germination conditions occur.

There are two important considerations for the maintenance of Mt. Baldy, which follow directly from the preceding discussion. First, a sand source on the windward side (lakeward) of Mt. Baldy must be artificially provided in order to maintain foreslope building and dune growth. Second, the foreslope of Mt. Baldy must be protected from wave erosion at its base in order to maintain the foreslope sand for transport by the wind field during dune migration. The first maintenance consideration is necessary only if continued dune growth is desired. However, the second maintenance consideration is necessary to assure the protection of the existing active Mt. Baldy dune structure.

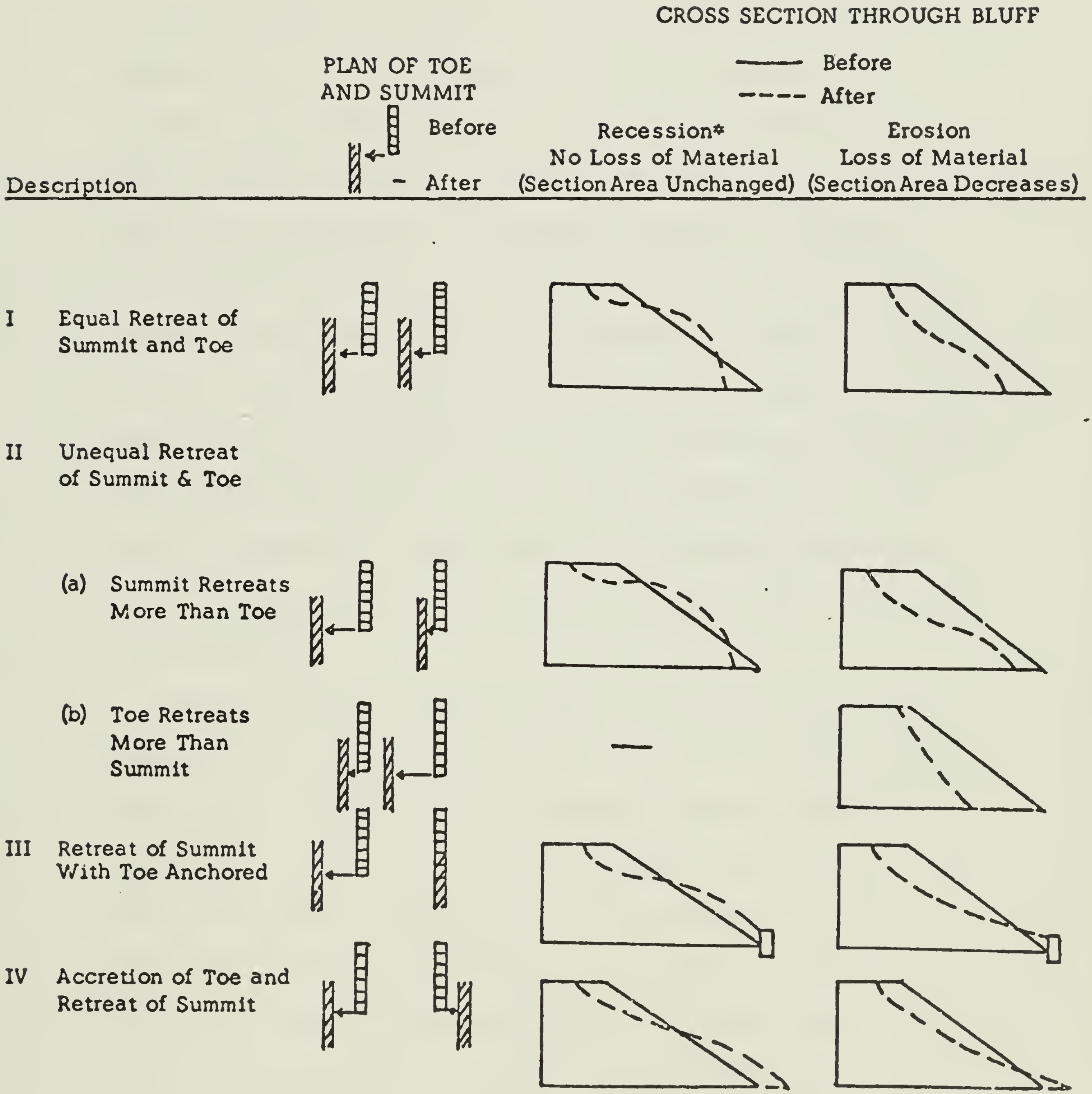
Recession and Erosion of the Beach and Dune Bluff

The National Lakeshore coastline experiences periods of recession and erosion which occur either concurrently or separately depending upon the mean water level and storm wave conditions. The variability of long and short period lake level fluctuations complicates the evaluation of recession and erosion rates. For the purpose of this

report, erosion is defined as a loss of material from a cross-sectional area of beach or dune and recession is defined as the retreat of a specific point on a cross-section of the beach or dune with no necessary loss of material. Stated in more generalized terms, erosion is related to the net loss of material while recession is related to topographic changes with no necessary net loss of material.

There are three specific points on a beach-dune profile which are normally referenced when evaluating recession rates; waters edge, toe of dune, and top of dune bluff. Of these three, waters edge is clearly the most ambiguous reference point for determining recession rates. For example, the annual lake level cycle produces a recession and advance of waters edge regardless of the occurrence of simultaneous erosion and deposition. Furthermore, the onshore-offshore movement of beach material during constructive or destructive beach cycle phases increases the complexity of interpreting waters edge as an indicator of beach erosion rates.

The use of toe of dune or top of dune bluff measurements to determine recession and erosion rates provides a degree of improvement over waters edge, but these measurements are also difficult to interpret directly. Figure 2 shows the various toe and dune bluff (summit) changes which can be anticipated for a coastal dune foreslope. This series of diagrams illustrates the complex nature of foreslope variability and supports the arguement that recession rates cannot be directly interpreted as erosion rates.



*For this report recession is defined as: movement with no erosion.
(from Bird and Armstrong, 1970)

FIGURE 2

The purpose of the preceding discussion is to develop an appreciation for the following evaluation of beach and dune recession and erosion rates along the National Lakeshore coastline. Previous estimates of shoreline recession rates (Powers, 1958; Corps of Engineers, 1971; Moffatt and Nichol, Engineers, 1975) and volume change rates (Corps of Engineers, 1971; Moffatt and Nichol, Engineers, 1975) have presumed that there is a direct constant relationship between these two rates. Thus aerial photographs have been used extensively, in conjunction with hydrographic data, to determine recession rates. These recession rates have then been converted to volume change rates (erosion rates) based on the assumption that recession and erosion are corresponding physical processes.

Both the Corps of Engineers (1971) and Moffatt and Nichol, Engineers (1975) initially considered a conversion factor of one cubic yard of material loss for each square foot of recession (one linear foot of recession over a one foot unit cross-section). This figure, which was derived for use on ocean beaches, is based upon the average height of the beach berm above mean water level and the depth of the zone of significant wave base. (Approximately +10 feet and -17 feet respectively for ocean beaches.) Moffatt and Nichol, Engineers (1975) arrived at a conversion figure, for the study area, of 1.63 cubic yards of erosion per square foot of recession by assuming an average dune bluff height of +30 feet and an effective

depth of significant wave base of -14 feet. Using this conversion figure and data on bluff recession (from 1966 to 1973) they estimated an annual "probable" volume loss of 189,000 cubic yards per year for the approximate coastal region of this study. They also estimated that the annual background erosion was 74,000 cubic yards or 40% of the total. The Corps of Engineers (1971), utilizing the one cubic yard to one square foot conversion figure and shoreline advancement rate data (from 1894 to 1923), estimated the annual rate of accretion east of the Michigan City breakwater at 55,000 cubic yards. This figure corresponded closely to their net annual drift of 64,000 cubic yards, calculated from estimated incident wave conditions along the coastal area of this study. The difficulty inherent in using these estimated erosion figures can be appreciated from the above calculations. One method estimates net annual drift through the study area at 60,000 cubic yards (Corps of Engineers, 1971) to the southwest while the other method estimates net annual erosion volumes within the study area at 200,000 to 300,000 cubic yards.

These high net erosion volumes resulting from the extrapolation of shoreline and dune recession rates are most likely in error. This error is maximized by the use of dune bluff recession rates, because of the numerous modes of foreslope adjustment that can occur, Figure 2.

During periods of severe storms occurring at high lake levels the relationship between dune bluff recession and erosion would be most appropriate. However, once the foreslope is initially eroded,

either by direct wave action or slumping, it is subjected to numerous degrading forces such as wind, rain, and run-off. Thus dune bluff recession rates would be anticipated to be high for a considerable period of time following initial destabilization, regardless of the long period lake level or short period storm behavior. Specifically, even after the current period of high lake level subsides, dune bluff recession rates may remain high while erosion rates will tend to decrease as foreslope material readjusts during stabilization.

Another error in the net erosion volume estimates results from the linear extrapolation of recession rates over large horizontal distances along the dune bluff. This type of extrapolation assumes that the physical and biological characteristics of the dune bluff are the same along the entire study reach. As will be shown in a later section, differential recession and erosion is occurring throughout the National Lakeshore coastline as a function of physical and biological variations on the beach and dune.

EFFECTIVENESS OF BEACH NOURISHMENT

Introduction

The purpose of this section is: to review the status of the beach nourishment project at the National Lakeshore; to discuss the future of the beach nourishment project if it is not maintained; and to discuss some general considerations for the use of beach nourishment in future projects within the National Lakeshore. The first two sections are brief since a great deal of this information has already been presented to the National Park Service, in Progress Reports No. 2 and No. 3 on the Indiana Dunes National Lakeshore Monitoring Program, Corps of Engineers Contract No. DACW23-75-C-0041.

Review of Beach Nourishment Project

In the Spring of 1974 a beach nourishment project was completed along a 3000 foot section of National Lakeshore coastline in front of Mt. Baldy. The purpose of the beach nourishment was to protect the rapidly eroding foreslope of Mt. Baldy and to supply material to the littoral drift for the mitigation of beach and dune erosion to the southwest of the project area. The estimated amount of nourishment material placed on the beach was 226,670 cubic yards based on contract specifications. In Progress Report No. 2 (1975) the amount of nourishment material estimated to actually have been placed on the beach was revised downward to 201,482 cubic yards. Table 1 shows the accumulated volume loss and volume remaining, based upon

Time Ending	Volume Remaining (in cu. yds.)	Percent Volume Loss (226,670 cu. yds.)		Percent Volume Loss (201,482 cu. yds.)	
		Period	Total	Period	Total
June 1974	139,870	38%	38%	31%	31%
December 1974	101,960	17%	55%	18%	49%
April 1975	59,500	19%	74%	21%	70%
October 1975	53,356	3%	77%	3%	73%

Table 1. Volumetric changes in beach nourishment.

both of these initial estimates. It is difficult to assess the volume loss rate prior to June 1974 because of the lack of survey data during the actual placement of the fill. Approximately 80,000 cubic yards of nourishment were eroded from the beach during the first twelve months of the monitoring period. The rate of erosion appears to be slightly higher prior to June 1974 and appreciably lower after April 1975.

The average shoreline recession for the 3000 feet of beach nourishment is shown in Table 2. The average rate of recession calculated from these data is 79 feet per year. The volume loss, given in Table 1, is calculated for a section of beach nourishment profile extending from +9 feet to 0 feet LWD. Utilizing the erosion estimation technique discussed in the previous section of this report, a recession to erosion rate conversion factor for a section of this thickness would

Time Period	Number of Days	Shoreline Recession (feet)
16 May to 6 June (1974)	21	-18
6 June to 25 July (1974)	49	-23
25 July to 6 September (1974)	43	- 2
6 September to 24 October (1974)	48	- 8
24 October to 4 December (1974)	41	-13
4 December to 13 April (1975)	130	-27
13 April to 1 October (1975)	172	-18

Table 2. Average shoreline recession between ranges SR-12 and SR-17.

be 0.33 (one foot of recession is equivalent to 0.33 cubic yards of erosion per foot of beach). Calculating the estimated erosion from the average observed recession rate would give a value of 78,000 cubic yards of loss. This value compares favorably with the estimated volume loss of 80,000 cubic yards calculated from survey data using precise end area volume techniques. This result strongly supports the statement made earlier that the volume loss due to shoreline erosion can be estimated from average bluff recession rates when direct wave attack on a foreslope is enhanced by high lake level.

In order to compare the estimated erosion rates for the beach nourishment area with the volume loss calculated from measurements taken at the beach nourishment site, a set of erosion calculations were made from the Moffatt and Nichol, Engineers (1975) data. Table 3 shows the "probable" recession rates at three ranges which are in and immediately adjacent to the beach nourishment. The "probable" recession rate used by Moffatt and Nichol, Engineers (1975) is one half the observed recession rate for the time period from 1966 to 1973. This scaling was chosen to provide a representative average recession rate for the wide range of lake level variation which is known to occur on a long period basis. Using these data and the 1.63 cubic yards of erosion per foot of bluff recession relationship the calculated annual volume loss for the 3000 feet of beach nourishment is 48,900 cubic yards.

Range No.	Probable Recession (ft/yr)	Average Recession (ft/yr)	Distance Between Ranges (ft)	Area (ft^2)
19 - 1	9.0			
		9.5	1,770	16,815
19 - A	10.0			
		10.5	1,680	17,640
19 - B	11.0			
			3,450	34,455

Table 3. Average annual area of bluff erosion within the beach nourishment area. (After Moffatt and Nichol, Engineers, 1975.)

This volume is considerably smaller than the 80,000 cubic yards value calculated earlier.

Moffatt and Nichol, Engineers (1975) recognized the increased erosion possibility for the proposed beach nourishment and calculated an overfill ratio using the +9 foot (berm height) and the -14 foot LWD limits. This overfill estimate was 2:1 meaning that twice as much fill would be required to sustain the estimated erosion rates. Refering back to Table 3, the average recession rates estimated from this overfill consideration, would be 19 to 21 feet per year. Calculating the average annual erosion volume for the beach nourishment area from +9 feet to -14 feet LWD gives a value of 51,100 cubic yards which is still substantially less than the actual loss calculated from the nourishment monitoring data. Lastly, if these overfill estimates are applied to the region between +9 feet and 0 feet LWD, then the estimated volume loss is 19,800 cubic yards.

The conclusion which can be drawn, from these various recession and erosion rate calculations, is that the design specifications for the original beach nourishment berm were underestimated by a factor of 4. Further support for this conclusion is presented in Table 4. These recession rates, for the individual monitoring ranges, are substantially higher than the rates given in Table 3. In addition the recession rates in column I are for the period of lowest observed erosion (approximately 3% of the total nourishment volume lost). Careful consideration should be given to the preceding data before future design estimates are made on beach nourishment volume requirements.

Range Number	I	II
SR-11	- 3	+ 13
SR-12	- 5	- 19
SR-13	- 36	- 12
SR-14	- 37	- 17
SR-15	+ 3	- 37
SR-16	- 23	- 40
SR-17	- 12	- 34
SR-18	- 19	+ 19

Table 4. Individual shoreline adjustment rates for ranges SR-11 to SR-18 from December 4, 1974 to April 13, 1975 (II) and April 13, 1975 to October 1, 1975 (I).

Non-Maintenance of Present Beach Nourishment

The failure to maintain the current beach nourishment project will result in severe erosion to Mt. Baldy and the adjacent bluff region. The amount of nourishment remaining in the area of Mt. Baldy is minimal (see Table 1) and the material which does remain is being rapidly eroded on the updrift (northeast) end. The observed volume loss between sequential ranges, Table 5, shows this rapid updrift erosion rate.

A major storm such as the March 1973 storm, could effectively eliminate the current beach nourishment. The exposure of the foreslope of Mt. Baldy would result in bluff recession rates comparable to those of the early 1970's (over 20 feet per year). Even if a major storm does not occur within the next twelve months, a substantial portion

Range Number	April - Aug. (1975)	Aug. - Oct. (1975)
SR-11		
	- 562	+ 1177
SR-12		
	- 1817	+ 531
SR-13		
	- 1098	- 198
SR-14		
	+ 360	- 1924
SR-15		
	+ 102	- 374
SR-16		
	- 944	- 780
SR-17		
	- 3173	- 2930
SR-18		
TOTAL		
(SR-12 to SR-17)	- 3398	- 2746

Table 5. Volume loss between ranges in cubic yards.

of the existing nourishment will be carried away in the littoral drift.

Future Beach Nourishment Projects

Beach nourishment is the best alternative for the National Park Service to use for mitigating beach erosion and maintaining a natural scene. It provides recreational benefit, contributes to the littoral drift, and maintains the natural appearance of the coastline. The discussion in the two preceding parts of this section point out the high loss rate which can be anticipated with this form of erosion alternative. However, other types of structural alternatives to beach erosion, which may have longer performance periods, would be unappealing to the natural scene.

The most important consideration in planning future beach nourishment projects is that the proper amount of material is selected for the desired period of performance. Specific recommendations for estimating this amount are not yet available, but they will be made available within the next twelve month period, as a result of ongoing erosion studies along the National Lakeshore coastline. It appears, at this time, that the nourishment volume estimates should be revised upward by a factor of four. If the results of the ongoing studies continue to support this figure, then cost considerations may become a limiting factor on the beach nourishment alternative.

Another factor which appears to be contributing to the high rate of erosion of the current beach nourishment is the actual design of the berm. The steep sloped front face of the berm is one of the most unstable configurations which could be used for beach nourishment placement. Alternative designs should be considered and evaluated for incident wave conditions at the National Lakeshore.

The selection of beach nourishment material should be made on the basis of availability, composition characteristics, and cost. The suggested use of offshore borrow material is reasonable and concern over the stability of the finer sediment size of this borrow material may not be necessary. Recent beach nourishment projects at Delray Beach and Jupiter Island, Florida have used fill material of substantially smaller mean diameter than the native beach sands

(Strock and Noble, 1975). The total volume loss at Delray Beach was 8% during the first year and Jupiter Island actually experienced a 5% gain in total volume. The reason for this low rate of erosion is not clear nor is it necessarily consistent with other projects using smaller than native beach sand sizes. However, careful consideration should be given to the selection of nourishment material size, beyond that prescribed by conventional engineering selection criteria.

COASTAL VEGETATION DISTRIBUTION AND ENVIRONMENTAL INFLUENCES

Introduction

The proceding sections of this report have concentrated on the physical conditions and processes which occur along the Indiana Dunes National Lakeshore coastline. The following section focuses on the characteristics, distribution, and environmental response of vegetation located within the study area of this project. Specific plant types which appear in this section are referenced in a detailed appendix (Appendix A) of this report. A second appendix (Appendix B) lists all of the vegetation which has been described as occurring in the coastal dune region of southern Lake Michigan, but which has not been identified by this field study.

Physical Characteristics of Embryonic Beach and Dune Sands

One of the most influential factors affecting vegetation in the beach-dune environment is the sand substrate. Barren beaches and dunes are subject to direct sunlight resulting in high levels of light intensity at the sand surface. The high reflectivity of sand causes light intensity, immediately above the sand surface, to be higher than normally encountered above other natural surfaces. The poor heat holding capacity of sand, due to its low specific heat characteristic, results in extreme temperature fluctuations over short periods of time.

In the early morning, following sunrise, the upper few inches of sand heat rapidly, leaving the lower sand levels relatively cold. The depth of warming increases slightly during the day but as the sun sets, the sand rapidly cools. This extreme and rapid change in substrate temperature creates a very harsh environment for most plant varieties.

Sorting plays a major role in the water holding capabilities of embryonic sand surfaces. Beach and dune sediments can range from well sorted (grains primarily of one size) to poorly sorted (wide distribution of grain sizes). A well sorted sand has large spaces between grains, which allow water to percolate quickly through the sand layers. In a poorly sorted sand these large spaces are filled with smaller grains. Therefore, the contact between the sand and water increases, increasing cohesion. This results in a reduction of the rate of percolation. However, even in a poorly sorted sand there is still less cohesion and capillary action than is normally present in other soil horizons. This means that water is quickly lost by percolation downward, in all sand substrates. Furthermore, any water remaining near the top of the sand is quickly lost by evaporation, especially during high wind and high temperature conditions. Therefore, water availability is determined at lower substrate elevations by either normal or perched water table levels. Above these levels, water availability is limited by rainfall and dew formed by condensation from moist night air on the cool sand.

Sand, by itself, has very little nutrient value and tends to maintain this characteristic due to rapid oxidation of any organic matter that is deposited. This oxidation retards the accumulation of humus on both dunes and beaches, even after vegetation has become established.

Vegetative Sequences on Beaches

The beach is considered to be that area of the shore that is influenced by wave activity. Cowles (1899) described the beach as being divided into three biotic zones; lower, middle, and upper; based on the environmental conditions that exist in each zone.

The lower beach is a vegetatively sterile sand environment, continually changing under the influence of waves. Any possibility for the establishment of rooted vegetation is prevented by waves, which dislodge the plant by removing the sand support. Only a few types of adapted algae exist here because of the alternate wetting and drying of the zone. The upper limit of the swash is the upper extent of the lower beach.

The upper limit of the mid-beach is the strand line formed during the most recent storm. It is here that storm waves deposit debris, dead insects, fish and driftwood. The continual wind action, coming off the lake, and direct exposure to the sun, subject this area to extreme desiccating influences. Only succulent annuals, with special adaptations against moisture loss, usually survive. Each year these plants depend on dispersal of a large number of seeds around the

driftwood and other energy reducing structures to protect them from the wind and allow time for germination and root establishment. Even if perennials germinate within the mid-beach region, they are usually removed by winter storm waves. The sand in the mid-beach is not as sterile as the lower beach mainly because of the decaying debris, but build-up of organic material is prevented by rapid oxidation and erosion.

The upper beach consists of that area above the strand-line which is not usually attacked by storm waves. This zone terminates at the base of the dune on the back beach. Conditions within this zone are less severe than the lower two beach zones because of rare wave activity. These conditions allow perennials to remain from year to year. However, high light intensity and xerophytic (dry and windy) conditions still persist, along with low nutrient levels of the substrate.

These zones have been defined mainly by biological zonation rather than physical or geologic parameters. This type of zonation is useful because of the wide range of beach configurations that can exist with the same enviornmental conditions for vegetation.

Vegetative Sequences on New Dunes

The concepts of embryonic and rejuvenated dune systems are important when considering the time required for dune succession to occur. Cowles (1899) describes dune succession as the natural sequence of vegetative changes that occur with time, as climatic and soil conditions are altered by the presence of vegetation.

Embryonic and rejuvenated dunes are the two main classifications of bare sand surface suggested by Cowles (1899). An embryonic dune consists of recently worked material that has not been stabilized for any great length of time. It is composed primarily of quartz sand with little nutrient content. Rejuvenated dunes contain some organic matter which has been layed down by pre-existing vegetation and subsequently covered over. It is not uncommon to have an embryonic dune form over an established or rejuvenated dune (Cowles, 1899).

The establishment of dune vegetation is dependent on many factors. The type of vegetation established is directly related to the plants that are available in reasonably close proximity to the dunes. This relationship exists because seed dispersal to a particular area on the dune usually requires chance events such as wind, animal, or human transport. The seeds must then lodge themselves in an area where favorable climatic conditions will initiate germination. Once the seeds have lodged they enter a critical period because favorable conditions must continue long enough to allow root anchoring. These conditions are dependent upon the moisture content and the presense of organic materials in the substrate. In addition, competition for space, nutrients, and water exists where vegetation is already present. Finally, even if conditions are correct for many varieties of seeds to germinate, only those plants adapted to the worst environmental conditions are going to successfully establish themselves.

Qualities Required By Pioneer Vegetation

The following characteristics are needed for the successful establishment of pioneer or primary dune forming vegetation. Seeds transported to a bare sand region where favorable growth conditions exist must germinate and establish roots quickly to prevent removal by the wind. Plant burial by sand is another hazard that must be overcome by high vertical extention capabilities of the plant.

Deep expansive root systems are necessary to hold sand in place and support wiry stems in an up-right position. In order to survive constant sand burial and erosion, roots should possess the ability to adapt to stem functions and stem-root functions.

Once a particular plant is established it must endure existing conditions through special vegetative adaptations. For example, a plant may develop waxy surface layers on leaves or develop a hairy bloom on stems and leaves to prevent moisture loss. It may also have roots that are capable of deep extension or rapid water uptake. Special genetic qualities allow different species to utilize low nutrient soils and withstand the thermal shock of rapid temperature fluctuations. However, these and other adaptive measures, present in the pioneer plants, are not always enough for success. There are no plants that are totally adapted to cope with all of the harsh environments present in an active dune system (Cowles, 1899).

The primary function of pioneer plants is to establish themselves and then alter existing conditions enough to allow a second plant society to develop.

The presence of pioneer plants changes the energy conditions, captures sand, and increases nutrient conditions by adding organic material which in turn increases the moisture holding capability of the sand. The shade provided by the plants results in lower sand temperatures. These new conditions make it possible for the next stage of succession to establish itself and slowly eliminate the pioneer plants. As each plant in the new successional stage inhabits the favorable environment, it immediately begins the slow process of creating favorable conditions for the next plant type and unfavorable conditions for itself. Cowles (1899) indicates that, without constant burying conditions, pioneer plants lose their vigor and decline in number. If burial resumes, vigor is restored.

Qualities Required by Secondary Vegetation

Perennial dunes require perennial dune forming and holding plants. Once the dunes have been formed and partially stabilized, the dune holding plants quickly follow. Conditions such as high surface wind energy and sand erosion and deposition have been reduced by the pioneer plants. However, many of the same characteristics for environmental adaptation are still needed by the dune holding plants.

The rate of germination and initial growth rate of the dune holders is less critical in the protected environment. However, the stability of the plant is more dependent on extensive lateral propagation of the root and rhizome structures.

Burial can still be a problem to secondary vegetation even after initial stability occurs. The ability to grow through the sand after burial occurs not only saves the secondary plant, but is instrumental in continuing the vertical expansion of the dune. Plants which lack this adaptation are quickly eliminated. In conjunction with this fast stem elongation, is the favored trait of buried stems being able to send out roots. This is an important characteristic for the tree type dune formers and holders.

Secondary vegetation has a higher moisture and nutrient requirement and lower tolerance for rapid temperature fluctuations than pioneer plants. Favorable conditions must remain within the limits of the plants tolerance if the plant is to survive. If high energy conditions greatly disturb the protected environment, pioneer vegetation must return to recolonize the exposed sand. The organic matter already present, before the disturbance occurred, can cause the recolonization to occur at a faster rate. This recolonization cycle makes it possible to have many different stages of succession within the same area.

Secondary successional plants are mainly responsible for the great vertical and horizontal growth of dunes. However, it is not uncommon to find deep sinuous valleys, within the dunes, where secondary vegetation was unable to establish and hold the sand effectively.

Tertiary Vegetation Establishment

Tertiary plants move into an area after the dunes have had time to become relatively stable structures. Usually, younger sets of dunes have already begun to form lakeward, protecting the older dunes from the direct effects of high wind erosion and deposition. Factors which determine the establishment of tertiary vegetation are: the dune slope to sun angle, the wind conditions regulating moisture, the extent of successful humus capture, and the depth of the water table level below the surface of the sand. Drifting sand may still create problems for tertiary plants that have very low tolerances for burial. Exposure of root systems can also destroy certain tertiary plant varieties. As new dunes block the wind, moisture levels increase dramatically in the low areas and create excellent capture basins for large amounts of organic matter. These areas can develop into isolated areas of mesophytic forest types characterized by high moisture and high nutrient requiring plants. As long as the ridges between the harsh lake condition and these isolated climatic regions are not breached, the tertiary vegetation persists. The persistence of tertiary vegetation is limited by their biological characteristics. Adaptations to harsh conditions are not present as in the other plant types. Nutrient and moisture content in the soil is usually required to be at higher levels than that of embryonic and secondary environments. The time required for tertiary vegetation to establish itself is noticeably longer because of the more stable environmental conditions

which makes rapid growth unnecessary.

Classical Dune Succession

Classical dune succession refers to the sequential change of environmental conditions and vegetation types caused by the interaction of regional climate, wind conditions, topography and vegetative characteristics. Traversing from the harsh beach to the milder dune environment reveals that the number of plant types able to negotiate the milder conditions increases. This increase in diversity increases the complexity of plant associations and also increases the density of shaded area.

The following discussion describes the concept of normal classical succession applied to an actively developing coastal dune system. It is assumed, during this discussion, that an active sub-aerial depositional environment exists as a sand source for new dune formation, by winds blowing off the lake. Therefore, the dunes would be youngest near the lake and become progressively older in the landward direction. This coastal dune system is analogous to the coastal dune system in the Indiana Dunes National Lakeshore. This discussion of classical succession describes a sequence of events which probably occurred along the southern Lake Michigan coastline following the last glacial retreat.

Initially a lower beach forms along the edge of the lake as the water level slowly drops. Microscopic examination of this beach reveals that only certain types of algae are found, intermingled with the sand grains.

Sand continues to build this area into a middle-beach washed only by winter storm waves. Succulent annuals can now establish themselves among the material at the strand line. _Cakile_, _Corispermum_ and spurges can return each year, by seed propagation, and survive due to their adapted characteristics. As the lake lowers, the beach continues to move lakeward and sand builds higher into an upper beach. Waves reaching this area are extremely rare, allowing the vegetation to remain from year to year. Annuals and biennials are the dominant plant types with a few interspersed perennials. _Artemisia_, thistle, spurge, cockle bur, evening primrose, _Cakile_, and _Corispermum_ constitute this community. As time progresses, transient dune features form and are destroyed with such frequency that normally only bare sand surfaces persist.

Drifting sand is initially captured by perennial marram grass, which is well adapted to high energy environments. After a small dune has formed, milkweed, equisetum, and other grasses establish themselves, creating an embryonic dune. The beach continues to build lakeward with falling lake level and sand deposition. This allows more embryonic dunes to form in front of the initial dune. A new type of vegetation begins to develop in the partially protected lee side of the dune crest. Dune builders and holders such as marram grass, wild rye, sand reed grass, willows, cherry, grapes, and cottonwoods are well adapted for existence on these advancing lee slopes. Cottonwood dunes dominate as the largest features in the coastal dune system. These features create protected areas landward, as they increase in

size. The lower wind energy landward from the coast coupled with the protection provided by the large cottonwood dunes, creates a stationary dune ridge in the back dune region. Wide plant diversity is now possible because of the low energy environment. The original grasses remain, but they become interspersed with milkweed, dogwood, junipers, little bluestem grass, beard grass, pines, grape, Viburnum, virginia creeper, equisetum, ragweed, goldenrod, panic grasses, sunflowers, and evening primrose. Small coniferous forests may establish themselves in low depressions between dunes where the moisture is high and direct wind energy low. The slightest change in these well protected areas could completely remove these pine environments. Under normal circunstances the pine environment develops quickly into a black oak forest with all of its associated understory. However, a combination of factors in the study area have limited the advancement of the dune succession to a black oak forest. The complexity of these factors is beyond the scope of this report.

Disturbances in a Stable Dune Environment

Most of the dunes in the study area are subject to reactivation by high energy storm events. This continuous sequence of reactivation and developmental succession results in all of the stages of normal succession being present within the study area at any given time. The degree to which normal succession is set back depends upon the intensity and duration of the disturbance. Figure 3 is a successional

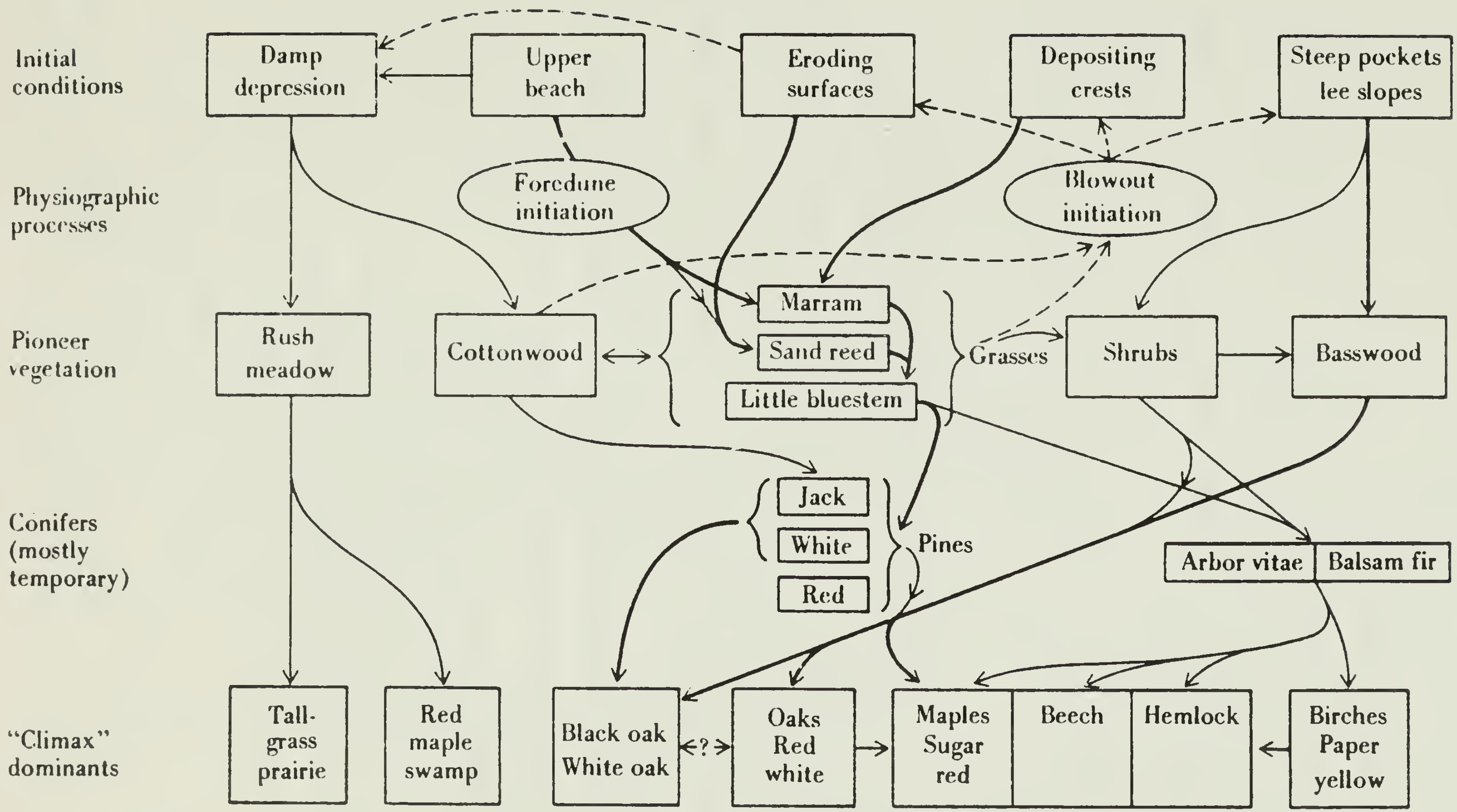

Initial conditions
Physiographic processes
Pioneer vegetation
Conifers (mostly temporary)
"Climax" dominants
Damp depression
Upper beach
Eroding surfaces
Depositing crests
Steep pockets lee slopes
Foredune initiation
Blowout initiation
Rush meadow
Cottonwood
Marram
Sand reed
Little bluestem
Grasses
Shrubs
Basswood
Jack
White
Red
Pines
Arbor vitae
Balsam fir
Tall-grass prairie
Red maple swamp
Black oak White oak
?
Oaks Red white
Maples Sugar red
Beech
Hemlock
Birches Paper yellow

FIGURE 3

flow chart from Krebs (1972) which indicates the various successional sequences associated with varying levels of disturbance. The diagram is greatly oversimplified, but presents a general representation of the normal successional pathways. The dashed lines indicate disturbances and the solid lines indicate natural succession. The time scale of the diagram is highly variable dependent upon climatic conditions, soil conditions, and available vegetation.

Distribution of Vegetation in the Study Area

Vegetation mapping was carried out through the use of aerial photographs, *in situ* transect line surveys and regional field investigations. Conventional aerial photographic techniques (see Stafford 1968, 1972) were used to map vegetation changes, within the study area, from 1939 to 1975. These maps were constructed to show large scale changes in vegetation distribution patterns.

A series of eight transect lines (Figure 4) extending from the shoreline inland across the study area were mapped in detail to show the specific distribution of vegetation types. The location of these lines was chosen so that all representative vegetation areas, which occur within the study region, would be shown on at least one transect line. These profiles also show the classical succession sequences which occur in the area.

The following paragraphs describe, in extreme detail, the vegetation assemblages which occur along each of the transect lines shown in Figure 4. These detailed descriptions are followed by a

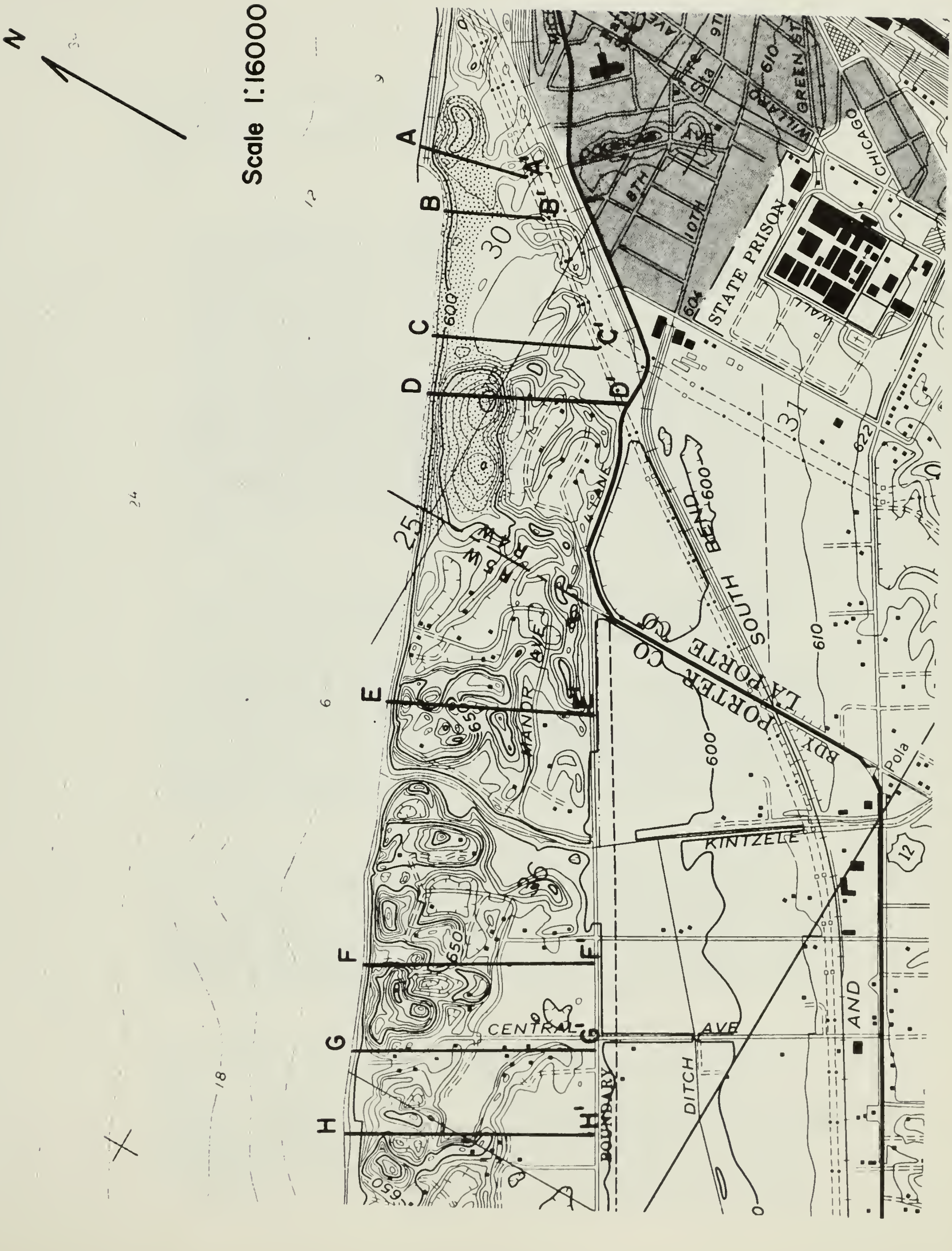

N
Scale 1:16000
A
A'
B
B'
C
C'
D
D'
E
E'
F
F'
G
G'
H
H'
STATE PRISON
CHICAGO
8TH
10TH
MANOR AVE
R 5 W
R 4 W
LA PORTE CO
PORTER CO
BDY
SOUTH BEND
KINTZELE
CENTRAL
AVE
DITCH
BOUNDARY
Pola
600
610
650

FIGURE 4

discussion of the relationship between the observed vegetation distributions and the environmental conditions within the study area.

Transect A-A' (Figure 5a): At the shoreline, a corrugated steel sea wall, constructed by NIPSCO, replaces the natural beach. A low sandy area extending from the wall to the base of the dune ridge is essentially barren. Vegetation in this area is widely scattered, occurring in the greatest abundance at the toe of the dune. Plants found in this area include clumps of Calamovilfa longifolia, Elymus canadensis, Typha sp and Solidago sp. Small scrubby trees, Salix nigra and Poplus deltoides occur in this area as well. Other associates are Cakile edentula, Helianthus sp. and Oenothera rhombipetala. The slumpting foreslope of the ridge is characterized by clumps of grasses, small trees and occasionally large toppled Populus trees.

The dune ridge runs parallel to the sea wall and trends south-southeast along the shoreline. The ridge is intersected by paths and depressions, but is presently stabilized with grasses and shrubs. Dense tufts of Ammophila breviligulata and patches of Ptelea trifoliata and Vitis riparia characterize the ridge. Other common associates include large Prunus virginiana clumps, Cornus stolonifera, tufts of Calamovilfa longifolia, Rhus sp. (a species of poison ivy or poison oak) and scattered Helianthus divaricatus. Morus alba also occurs infrequently in the area.

Immediately inland of the dune ridges, a southeast migration of sand is revealing an ancient forest, Figure 8a. The only living plants in this zone are widely scattered Corispermum hyssopifolium. Bordering this zone of moving sand, directly on the transect line, is a large isolated Prunus virginiana, Figure 8b. Erosion on the landward side of the shrub exposes the sand holding roots.

Farther inland, the transect crosses a wide, level depression with a sand and gravel substrate. Vegetation in this area is sparse and is characterized by tufts of Panicum virgatum, and widely scattered Ambrosia sp., Cirsium vulgare, Xanthium strumarium, Helianthus divaricatus and Verbascum thapsus. Other plants found in the area include Marrubium vulgare, Daucus carota and Euphorbia sp. Within the depression east of the transect line, a group of large

Quercus trees grow in a sandy soil. This stand of trees is not particularly dense, and undergrowth is similar to the vegetation in the rest of the depression.

Transect B-B' (Figure 5b): This transect crosses a narrow beach characterized by an exposed clay lense. Plants dominating the clay and sand beach are Typha, Equisetum hyemale and small Salix discolor shrubs. Immediately inland from the beach, the transect line crosses a steep bluff. The line then follows a gravel roadbed that separates two dune ridges. The ridges are currently held by dense growths of Ammophila and Calamovilfa. Other grasses occurring on the ridges include Andropagon scoparius and Elymus canadensis. Artemisia sp., Solidago sp. and Marrubium vulgare are common associates of the grasses. The roadbed is essentially barren, and sand freely migrates through the open space exposing roots of the grasses. Some small tufts of grass are present along the margin of the path while Corispermum and Helianthus divaricatus occur more frequently in the open portions of the path. Patches of the ridge holding grasses and associates extend over a level zone inland of the dunes. The grassy zone terminates at the edge of a depression, making an abrupt transition to forest vegetation. The forest is dominated by dense growth of large Quercus trees. The (understory) is primarily Sassafras albidum and Hamamelis virginiana. Pteridium aquilinum is also a frequent inhabitant of damp oak forest floors. Robinia pseudoacacia occasionally occurs at the forest margin.

Transect C-C' (Figure 5c): This transect crosses an essentially barren sand beach just beyond the eastern limit of the beach nourishment. Immediately inland of the steep bluff is an artificially planted zone. This wide sandy area is only sparsely covered by small tufts of the planted grass species. The rows of grass are occasionally interrupted by Asclepias cornuti, Helianthus divaricatus or Carex sp.

Landward of this planted area, a low slope grades into another level plain. In contrast to vegetation of the planted area, this portion of the plain supports highly diverse vegetation. Dense clumps of Ptelea trifoliata are characteristic of this zone. Clumps of various grasses including Ammophila and Calamovilfa cover much of the area. Common associates scattered throughout this zone are Corispermum, Verbascum thapsus and Carex sp.

Vitis riparia is a common inhabitant, usually trailing along the ground. Liatris scariosa, Verbena stricta, Phlox sp. and patches of Rubus sp. occur occasionally. Along an old overgrown roadway, Cenchrus tribuloides and Helianthus divaricatus are predominant. Isolated large trees, Robinia pseudoacacia and Malus sp., also grow along the abandoned road. Approaching the forest zone, the character species are, grasses Andropogon scoparius and Elymus canadensis. Small cottonwoods and their associates occur, along with a single small community of Yucca filamentosa. As on transect B-B, there is an abrupt transition into forest. The character species is Quercus velutina. Hamamelis virginiana and Sassafras albidum. Predominate as understory. Other associates include Smilax sp., Morus alba, Cornus stolonifera and Vibernum acerifolium. Pteridium aquilinum is a common ground cover.

Transect D-D' (Figure 6a): The beach along transect D-D' is separated by a berm into two distinct parts. The lower beach is devoid of vegetation, however, landward of the berm, the upper beach is very sparsely vegetated. The upper beach is composed of fill material and is several feet above the lake level. The most common plants inhabiting the upper beach are Corispermum and Cycloloma atriplicifolium. Small isolated tufts of Elymus canadensis, Calamovilfa longifolia and Setaria lutescens may also be found on the upper beach. Other plants occurring occasionally are Helianthus divaricatus, Xanthium strumarium, Oenothera rhombipetala, Cenchrus tribuloides, Artemisia sp., Ambrosia sp. and Amaranthus alba.

The foreslope of Mt. Baldy is barren, but scattered communities of Ammophila breviligulata occur on the top of of the dune. The grass forms steep-sided mounds, sometimes in excess of 12 feet in height, widely separated by zones of moving sand. The roots of the grasses are often exposed on the sides of the higher mounds. Corispermum has colonized the landward edge of the dune top. These plants are somewhat larger and less scattered than Corispermum found on the upper beach. The lee slope of Mt. Baldy is presently migrating over oak forest. Branches of overrun oak trees extend through the sand below the Corispermum zone. Many of the trees are dead, and some are entwined with Vitis riparia.

Landward of the leading margin of Mt. Baldy is an oak forest similar to those described earlier. The character species is Quercus velutina. Understory consists primarily of Sassafras albidum and Hamamelis virginiana, though Cornus stolonifera and Viburnum acerifolium are also present. In sandy areas near the dune, Artemisia sp. and Vitis ripario

may be found. Andropogon sp. and very small tufts of Miscanthus sinensis were observed near the back base of Mt. Baldy.

The transect emerges from the forest into a cleared, level area crossed by high power lines. Vegetation is diverse but sparse, and sandy substrate is exposed. Shrubs and small trees colonizing the area include Rosa sp., Salix sp. and Populus sp. Common associates are Ambrosia sp., Solidago sp., Xanthium strumarium, and Verbascum thapsus.

Although the western margin of Mt. Baldy does not lie on this transect, a survey was made of the grasses in the area. The western margin of Mt. Baldy is essentially stabilized by dense growths of grasses, except where foot paths cross the area. Five grasses occur with nearly equal frequency: Ammophila breviligulata, Calamovilfa longifolia Panicum virgatum, Andropogon scoparius and Elymus canadensis. The paths interrupting the dense stands of grasses are devoid of vegetation. The sand in these paths is often migrating through steep walled depressions, exposing grass roots, Figure 8c.

Transect E-E' (Figure 6b): This transect crosses a wide sandy beach and steep bluff. Clumps of vegetation are restricted to slumped material on the bluff face. Characteristic plants include tufts of Elymus canadensis, Cakile edentula and Helianthus divaricatus. Oenothera rhombipetala, Artemisia. sp., and Euphorbia sp. are also common slump vegetation. The top of bluff near the slope is inhabited by Vitis riparia, Elymus canadensis and Smilax sp. The top of the bluff drops off steeply landward, forming a narrow ridge. The lee slope of the ridge is held by grasses and small bushes. Near the top of the ridge Elymus canadensis and Vitis riparia are predominant species. Midway downslope there is a transition to Smilax, sumac (Rhus) and Hamamelis virginiana. Near the base of the ridge, oak and Sassafras albidum are characteristic. The damp, humus filled valley at the base of the ridge is stabilized exclusively by dense growth of large oaks and smaller Sassafras trees. A second (lower sloping) ridge, farther inland, is similarly vegetated. The lowest portion is dominated by Quercus and Sassafras, and shrubby clumps of Hamamelis appear farther upslope. On the second ridge top, where trees are less dense, grasses may be present as ground cover. Oaks are predominant over a sequence of ridges with Hamamelis and Sassafras as common understory. Typical oak forest extends to Beverly Drive. Natural vegetation is interrupted at several points along the transect line by private homes and roadways. The most notable clearing is near Manor Avenue where vegetation is restricted to lawns, decorative trees and shrubs.

Transect F-F' (Figure 7a): This transect line crosses a barren, sandy beach and high steep bluff. Vegetation is essentially limited to tree roots protruding from the bluff face. At the top of the bluff is an oak forest similar to those described earlier. Characteristic understory is Hamamelis, Sassafras and Smilax. The line continues across a forested valley and second ridge. Several private homes lie in the area adjacent to the line. Bounded by the high stabilized ridge on the north and Beverly Drive on the south is a wide level prairie. This particular area is representative of several prairie regions that occur landward of stabilized dune ridges. The prairie vegetation is both dense and diverse and grasses and shrubs are predominant. The northern margin of the prairie is inhabited by a small stand of conifers including Pinus resinosa and Juniperus virginiana. Dominant grasses are Andropogon scoparius and Muhlenbergia frondosa. Minor associates scattered throughout the grassy area are Daucus carota, Carduus nutans, Cirsium pitcheri, Pteridium aquilinum, Oenothera rhombipetala, Anemone virginiana, Marrubium vulgare, Verbascum thapsus, and rarely Opuntia rafinesquii, just west of the transect line shrubs are predominate. Clumps of Lonicera sp., Rosa virginiana, and Rosa nitida and patches of Rhus copallinum are also prevalant. Occasionally, a single large oak or sassafras may be found. The southermost portion of the prairie is characterized by small. often shrublike trees; Salix nigra, Prunus serotina, and Populus grandidentata.

Transect G-G' (Figure 7b): This line transects a barren beach and low bluff. Immediately inland of the bluff is a bowl-shaped depression. The open, lakeward margin is fringed with tufts of Andropogon scoparius, Ammophila breviligulata, and Calamovilfa longifolia. The walls and floor of the depression are partially stabilized by Ammophila and Calamovilfa; however, a large amount of moving sand is present. The landward boundary of the depression is a steep sand ridge. The lee slope of this ridge is held primarily by Vitis riparia. Large, scattered tufts of Ammophila breviligulata, Calamovilfa longifolia, Andropogon scoparius Elymus canadensis, and Panicum virgatum are common associates, especially at the base of the ridge. On the lee slope a shrublike form of Rhus (poison ivy, poison oak) is prevalant Asclepias sp., Marrubium vulgare Helianthus divaricatus, Solidago sp., and Yucca filamentosa occur infrequently. Though not directly on the line, Prunus virginiana occurs along the western margin of the ridge. The forested high bluff to the east of this transect supports growth of Tilia americana.

Just inland of the sand ridge, the line crosses a gravel parking lot. Vegetation around the lot is similar to the vegetation at the base of the sand ridge. A large Catalpa sp. tree is located near the lot.

The transect line crosses a bend in Central Ave. and continues through dense oak forest similar to those forests described on earlier transects. The forest vegetation is occasionally interrupted by clearings where private homes are located. Dense growth of large trees is characteristic landward to Beverly Drive; however, near the road, oaks are replaced by cottonwoods and willows.

Transect H-H' (Figure 7c): This transect line crosses a beach and steep bluff, both devoid of vegetation and continues landward across a grass-held dune. The lakeward margins are colonized by broad stands of Ammophila breviligulata. Moving inland, there is a gradual transition from Ammophila to Calamovilfa longifolia which occurs midway across the ridge. Both Calamovilfa and Andropogon scoparius are prevalent on the lee slope of the dune. Vitis riparia, Rhus sp., (poison ivy, poison oak) and communities of Cornus stolonifera, are common on the ridge flanks. Large, shrubby trees are scattered over the top of the ridge. These isolated shrubs include Prunus serotina, Prunus virginiana, Quercus velutina and Populus deltoides.

At the base of the lee slope of the ridge, there is an abrupt change to forest vegetation. Quercus sp. is dominant and Hamamelis virginiana and Sassafras albidum are common understory. Other associates include shrubs and small trees Cornus alterniflora, Cornus florida, Amelanchier sp. and the climbing vine Smilax hispida. Ceanothus americanus was observed once in this zone, Pteridium aquilinum is a frequent ground cover in valleys. The transect continues over several forested ridges, similar to those previously described and finally crosses a level prairie. Plants found in this region are similar to those found in the prairie of transect F-F'; however, a greater portion of this prairie is inhabited by shrubs, Salix and Populus. Near the southern margin, the prairie is interrupted by oak forest ridges, but Salix and and Populus remain characteristic of low area.

Vegetation Zonation Maps

Ten vegetation zonation maps, Figures 9 through 13, were generated using aerial photographs taken in 1939, 1955, 1960, 1967, 1969, 1970, 1971, 1972, 1973, and 1975. These maps show the distribution of grasses, shrubs and forests in the study area.

FIGURE 5

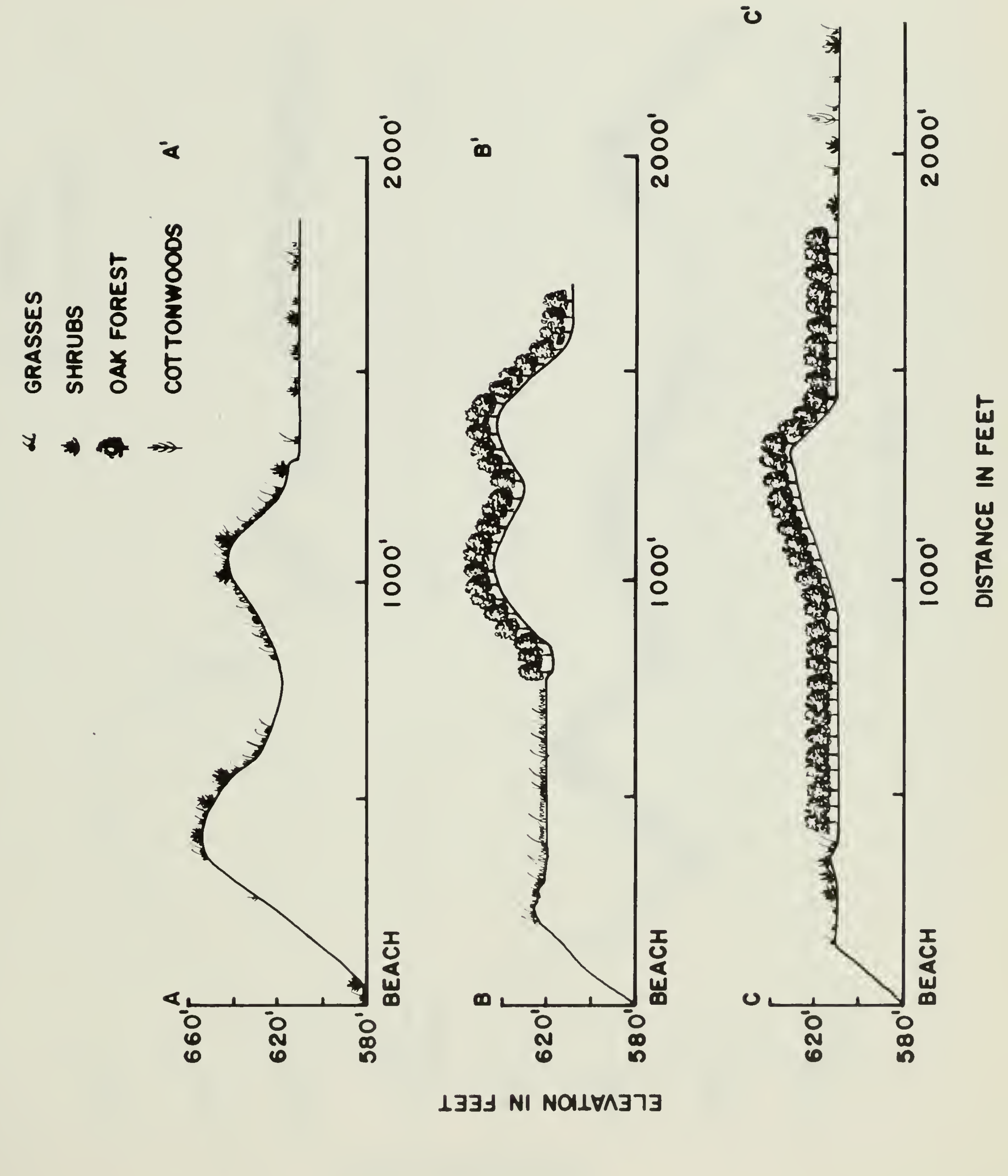
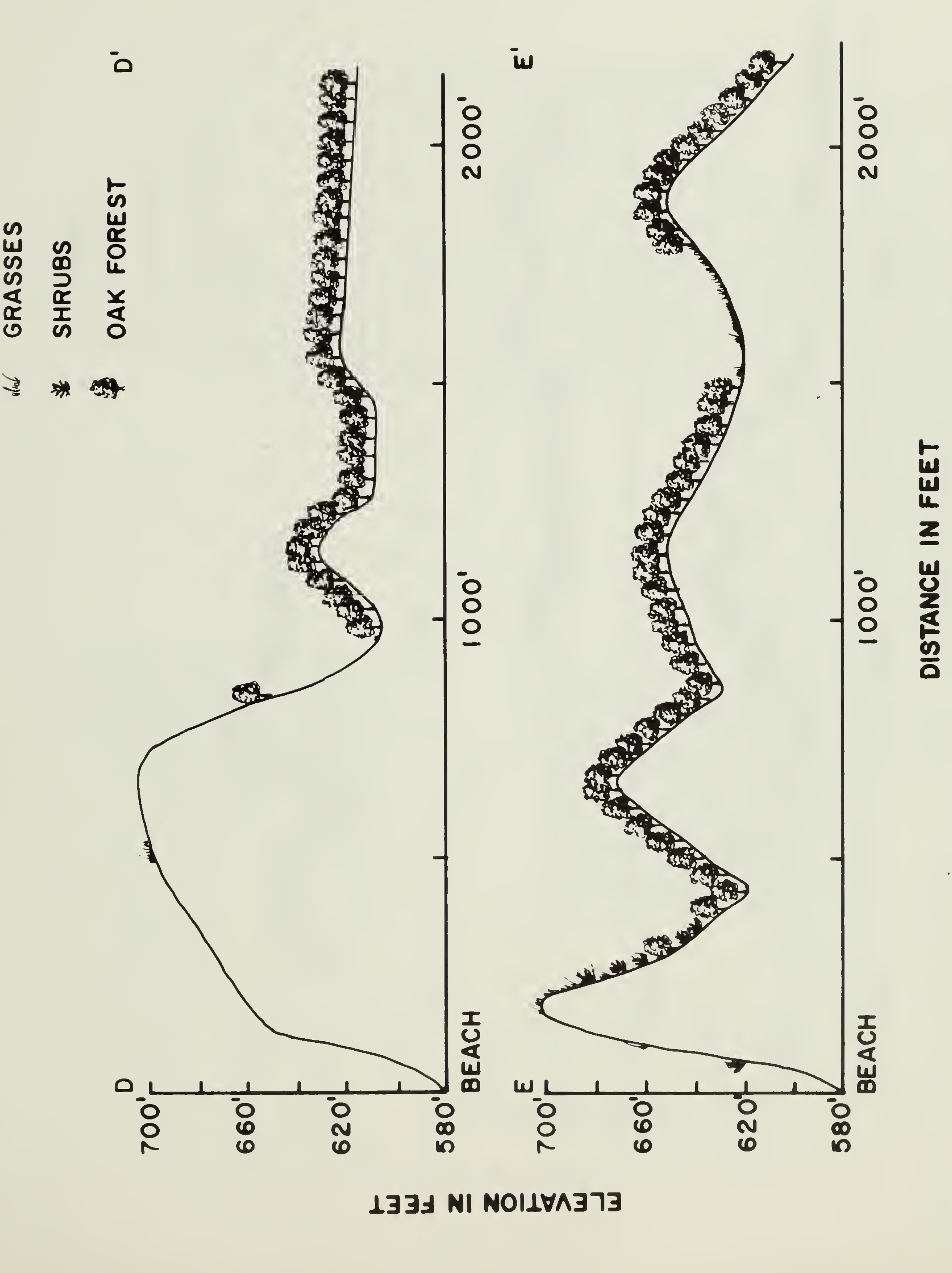

GRASSES
SHRUBS
OAK FOREST
COTTONWOODS
A
A'
B
B'
C
C'
660'
620'
580'
BEACH
1000'
2000'
ELEVATION IN FEET
DISTANCE IN FEET

FIGURE 6



GRASSES
SHRUBS
OAK FOREST
D
D'
E
E'
700'
660'
620'
580'
BEACH
1000'
2000'
DISTANCE IN FEET
ELEVATION IN FEET

FIGURE 7

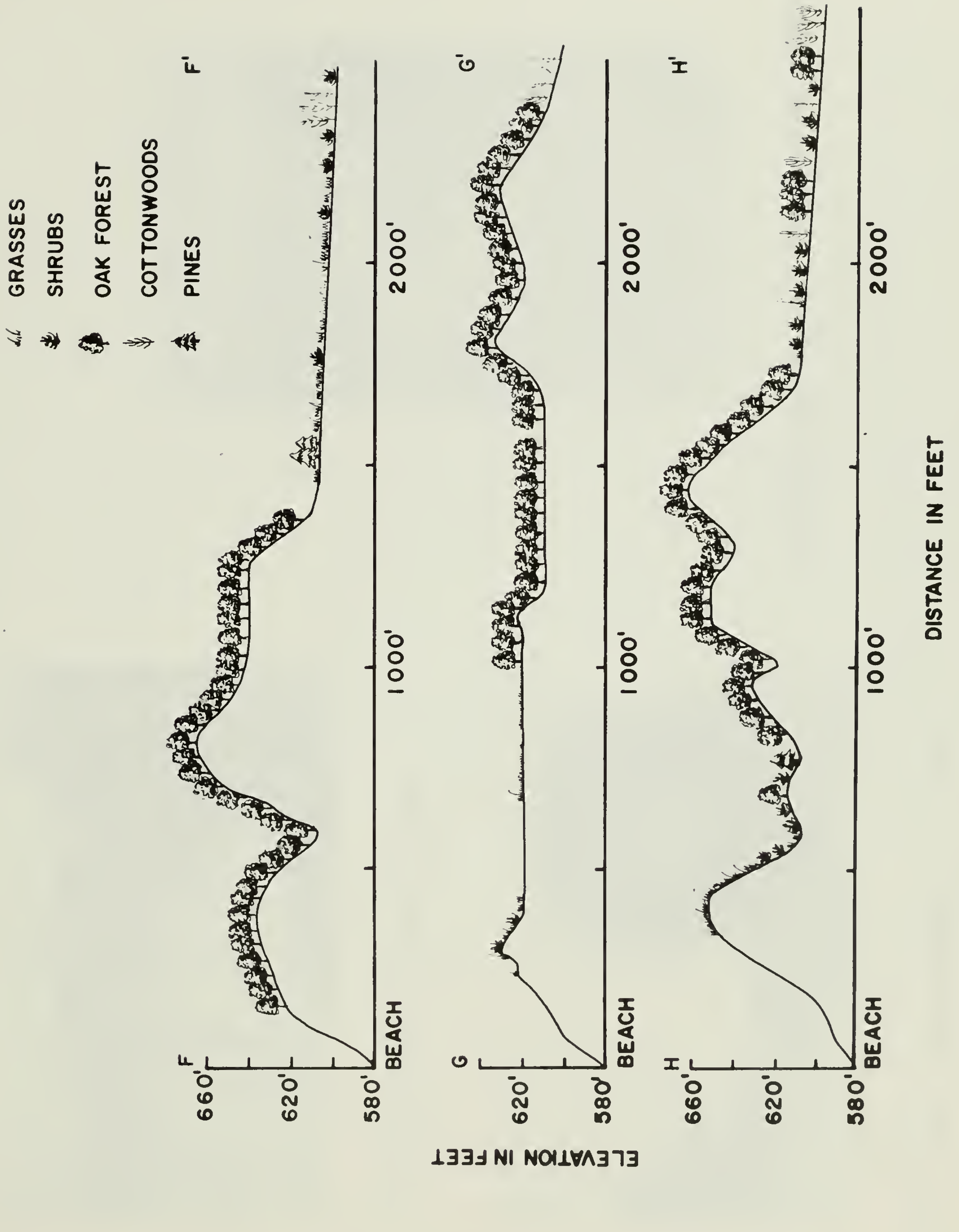

GRASSES
SHRUBS
OAK FOREST
COTTONWOODS
PINES
F
F'
G
G'
H
H'
660'
620'
580'
BEACH
1000'
2000'
DISTANCE IN FEET
ELEVATION IN FEET

FIGURE 8a. Buried Forest on Transect A-A'

FIGURE 8b. Large <u>Prunus virginiana</u> on Transect A-A'

FIGURE 8c. Wind Erosion of Human Path on Transect D-D'

A Zeiss mirror stereoscope was used to discern vegetation zone boundaries and to transfer the information to the maps. Field observations were used to verify the identification of each vegetation type indicated in the 1975 aerial photographs. The resulting vegetation maps are most useful in indicating areas of significant disturbance. The scale (approximately 1:8000) of the photographs used in constructing the maps make minor changes in plant distribution difficult to detect.

NIPSCO Region: The 1939 photograph (map, Figure 9) was taken at high altitude (approximately 1:16,000 scale) and resolution is poor; however, it clearly depicts the shoreline morphology prior to construction of the NIPSCO sea wall. By 1955, Figure 9, the shoreline has been cut back behind the sea wall. Large expanses of bare sand are indicated, but some areas of sparse grass cover may have been obscured by photographic overexposure. In 1960, Figure 10, some trees south of NIPSCO, along Beverly Drive, have been replaced by grasses. Grasses have stabilized the sandy area east of Mt. Baldy, while the shoreline appears to continually recede throughout the study area. Little change has occurred through 1967, Figure 10 and 1969, Figure 11. The grassy band along Beverly Drive near NIPSCO has broadened, apparently as a result of tree removal. As construction begins along the eastern margin of the study area, trees, shrubs and grasses are removed (Figures 11 and 12) resulting in a large zone of bare sand. In 1975, the region south of the NIPSCO wall remains barren though some grasses have reappeared along Beverly Drive.

Mt. Baldy and Minor Road Region: vegetation is not visible along the western flank of Mt. Baldy until 1960 (Figure 10) when grasses first appear. Vegetation cover increases until 1969 (Figure 11) and then appears to remain stable to present.

Apparent changes in grass patterns at the crest of Mt. Baldy may result from differences in photo quality or in the season when the photographs were taken.

A grassy area along the eastern portion of minor road is visible in 1939, Figure 9. This area is reduced in size by 1955 (Figure 9) by overgrowth of forest. Grasses are essentially eliminated in this area by 1960, Figure 10.

Development of Blowout West of Kintzele's Ditch: The sequence of maps from 1939 to 1975 depict the development of a blowout between Kintzele's Ditch and Central Ave. This structure is visible on more recent maps as a rounded extension of bare sand protruding into the forested area. In 1939 (Figure 9) the feature is just beginning to form. It continues to broaden and expand landward until 1975 (Figure 13) when it reaches a roadway.

Stabilization of Blowout West of Central Ave.: The blowout approximately 750 feet west of Central Ave., is devoid of vegetation until 1969 (Figure 11) when grasses are first visible. The area changes little in successive years, but appears to remain stabilized by the grass intrusions.

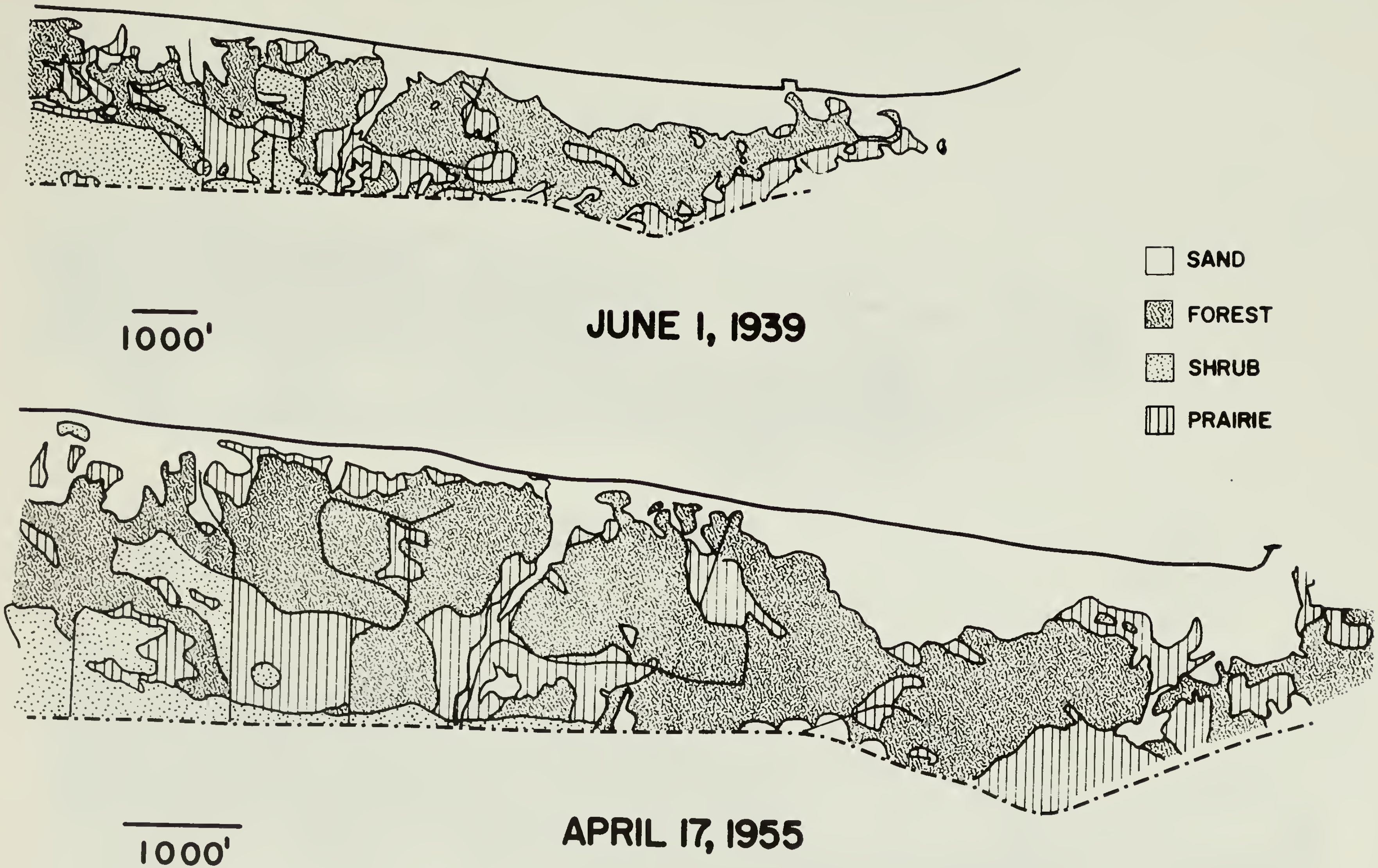
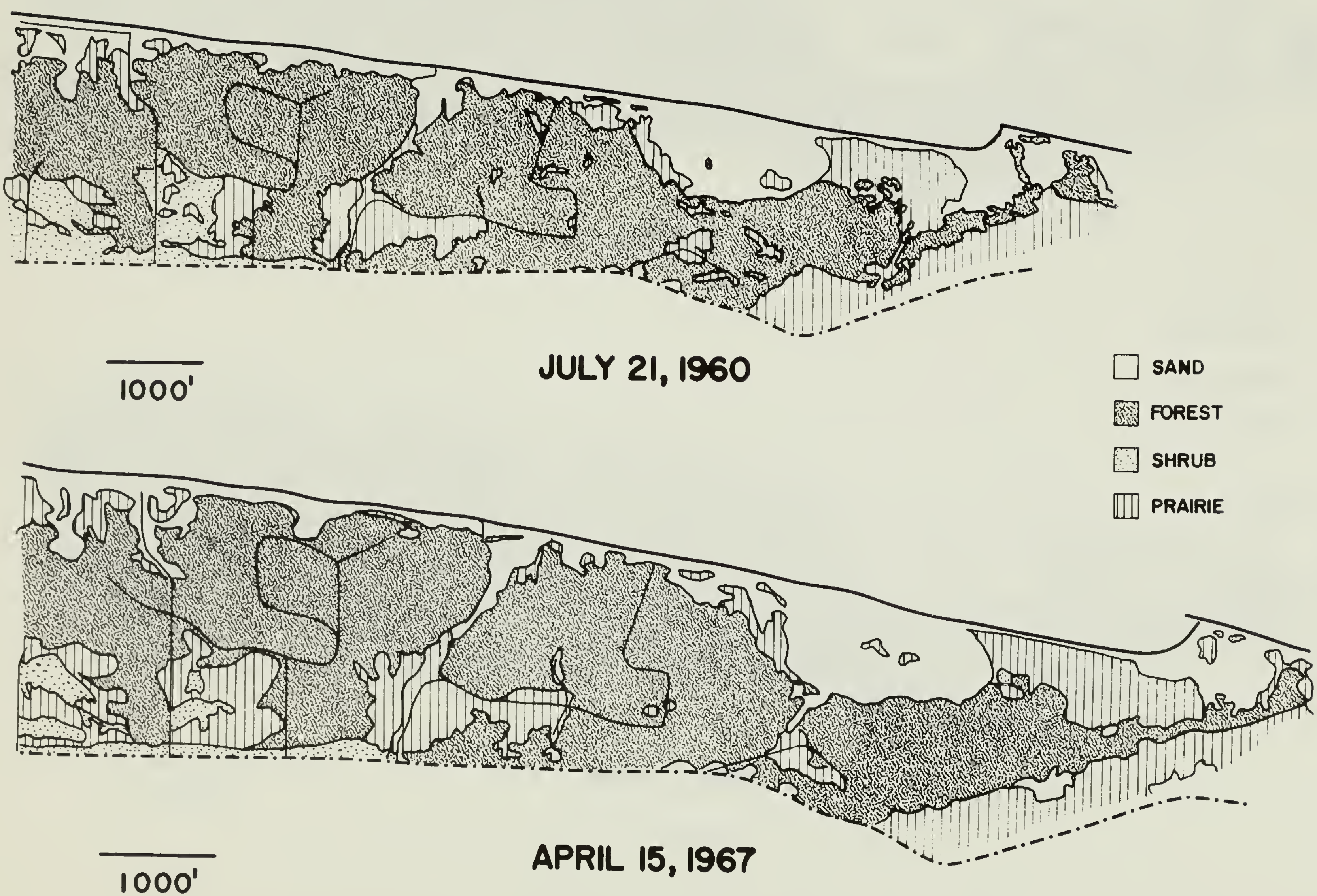

SAND
FOREST
SHRUB
PRAIRIE
1000'
JUNE 1, 1939
1000'
APRIL 17, 1955

FIGURE 9



JULY 21, 1960
1000'
SAND
FOREST
SHRUB
PRAIRIE
APRIL 15, 1967
1000'

FIGURE 10

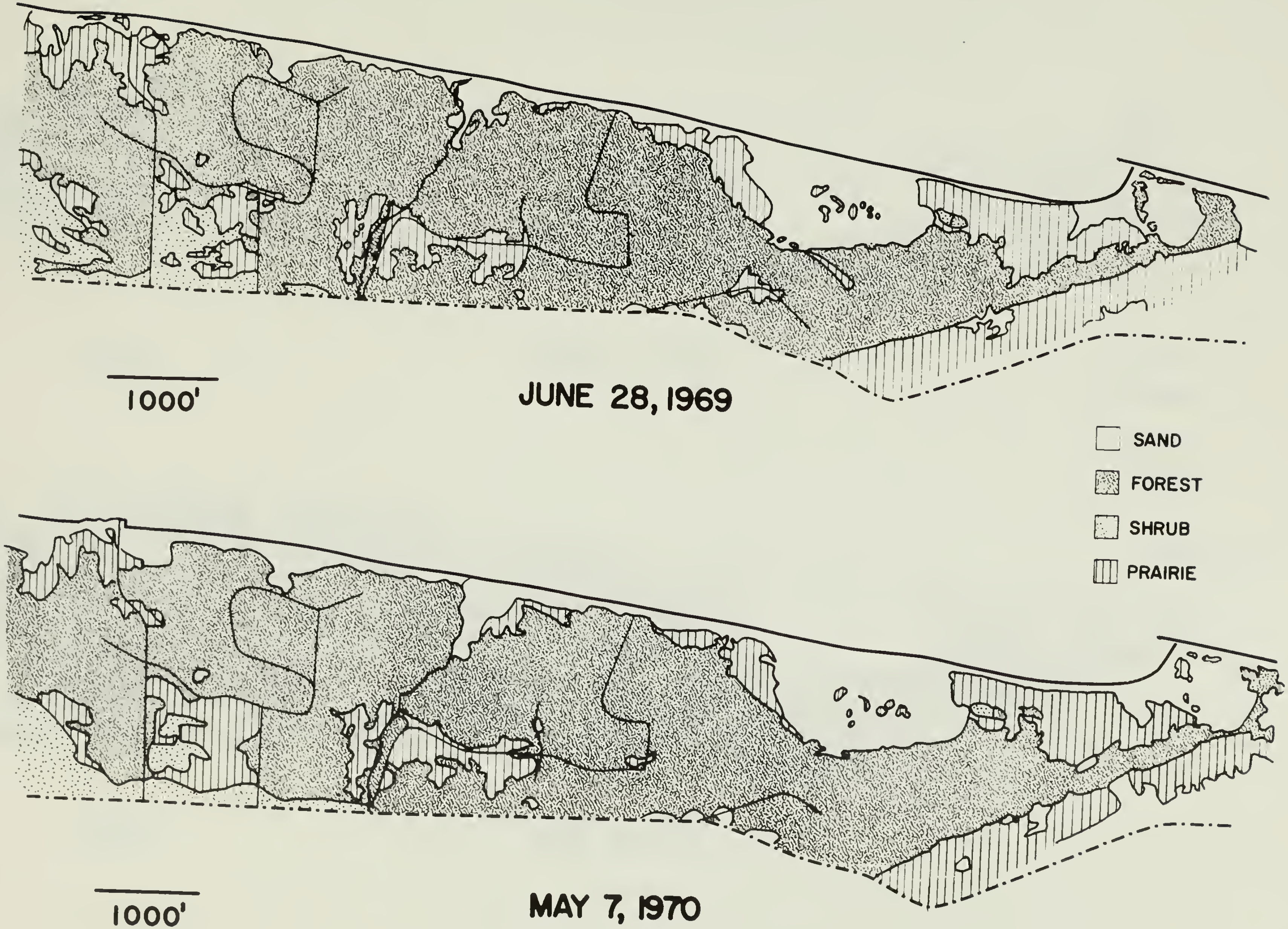


FIGURE 11

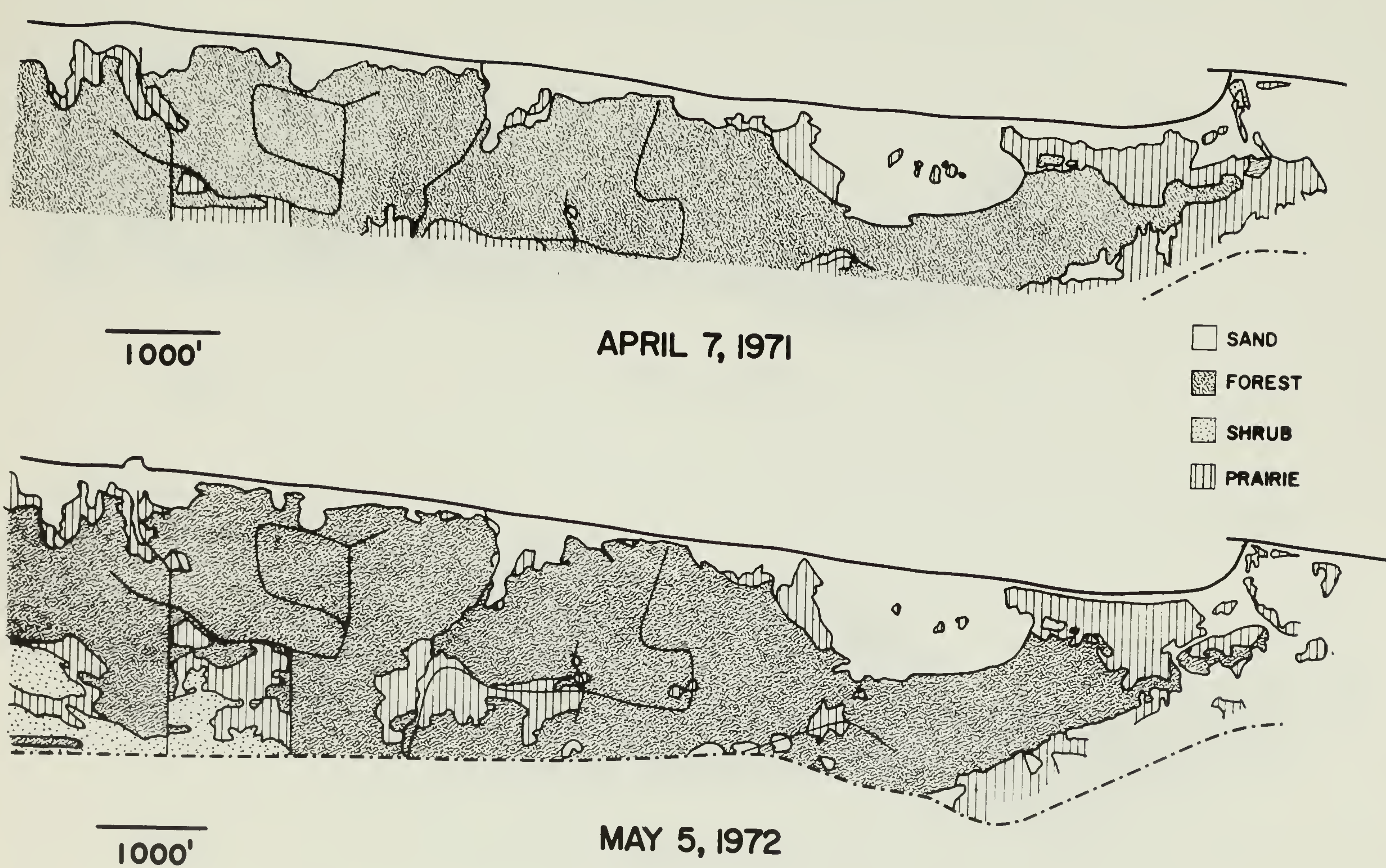


FIGURE 12

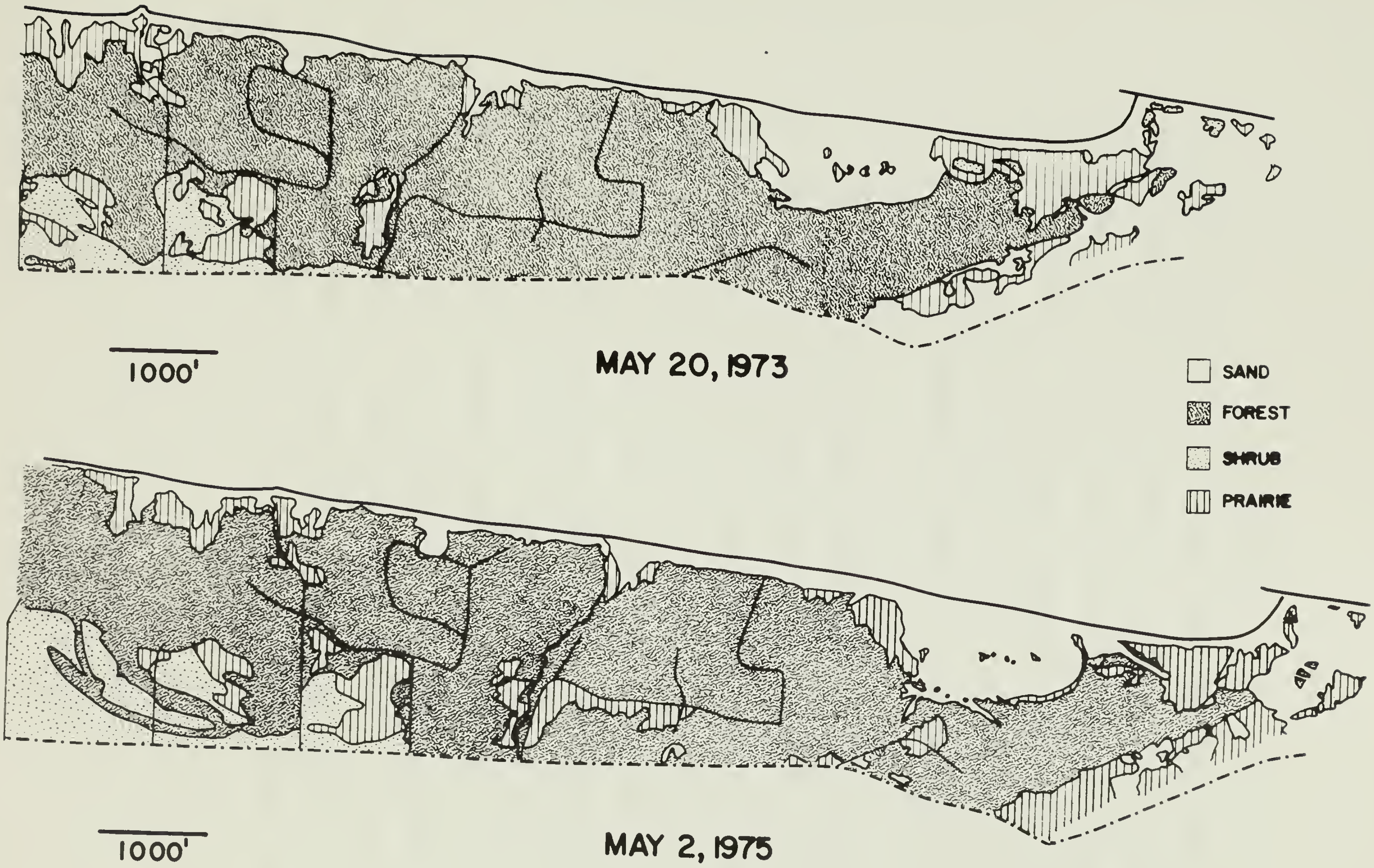


FIGURE 13

Discussion

The total study area is characterized by a black oak climax community which exists in protected areas behind the dune ridges. These communities are also present on the high bluffs, exposed by shoreline recession. The highest bluffs along the coastal back beach seem to correspond to areas held by trees and low valleys with grasses. The largest bare sand regions are mostly limited to the beach region.

A few isolated bare spots exist inshore and are associated with road cuts through the back dune or man made paths, large areas of moving sand, near the lake, show the typical southeast migration direction found all along the south shore of Lake Michigan. These features are most evident at 1) Mt. Baldy, 2) Kintzele's Ditch, and 3) east of Central Avenue. Vegetation types found on protected areas behind these migrating dunes reflect the low energy wind conditions provided by these natural barriers.

The sections of beach lakeward of the bluff toe exhibit typical successional plants. Slumping of organic material, on the bluff face, from what was once oak forest floor and partially stable grass areas has provided higher than normal nutrient levels of these slopes. This has allowed the invasion of higher nutrient requiring plants with xerophytic adaptations, severe conditions in this zone still prevent the embryonic establishment of pioneer vegetation on bare sand. The beach directly west of NIPSCO is characterized by a broad shelf of clay with a unique plant community that persists here mainly due to

the clay itself. Ground water seepage has been observed to be a relatively permanent characteristic which allows the creation of a hydrophytic environment with cattails and its associates. The impermeable clay layer catches water from surface percolation and other sources and channels it out onto the open beach. This seepage is a major factor in maintaining the clay exposures. Along the east bank of Kintzele's Ditch, another clay feature is exposed, above water level, which indicates frequent groundwater seepage. Other clay outcrops, west of Central Avenue, were observed, but were closer to present lake level. These areas also exhibited relatively constant seepage which kept sand from building up into a beach and caused greater erosion of the bluff. Moving back from the shoreline, protected low areas support different assemblages of plant types than are found on slopes and dune ridges. Vertical zonation patterns are observed which show a relationship between high moisture and high humus capture in depressions and dryer less rich soil horizons on slopes. There are also marked vegetative differences between north facing slopes and south facing slopes.

Patches of grass interspersed with oak trees generally characterize the southern half of the study area. These grassy areas are generally composed of prairie vegetation types which are common in disturbed forest areas. The prairies that exist in the study area seem to be in close proximity to roadways, possibly suggesting man as the main cause of the forest disturbance. However, there are many natural ways of opening the ground to direct sunlight which would initiate prairie growth. Several of these grass areas, near the east

end of Mt. Baldy and just west of minor road near Beverly Drive, show evidence of human intervention. Low shrubby stands are usually associated with prairie areas and are typically the first stages of recolonization of a destroyed forest area. The shrubs are also generally located near lower depressions and drainage ditches, where water can be found during periods of moderately dry weather. The diversity of plant life in a disturbed area can be used as an indicator of the frequency of disturbing forces acting on an area. Natural succession usually leads to greater diversity of vegetation types creating a more stable community.

The area west of Central Avenue is characterized by active sand transport and shows low diversity of species which are centralized in large masses with new species found only in their optimum areas of adaptation. In contrast, the prairie communities show high diversity of species and strong intermixing. This contrast exists because Central Avenue vegetation indicates a recently disturbed area and the prairie vegetation indicates a relatively stable ecosystem. Near NIPSCO, however, the model becomes complex because of the interaction with man. Even though the large number of species found could suggest stability the type of plants found (waste field types) are important. It is evident from the plant zonation maps, discussed earlier, that this area has been altered by man many times in the past. It is, therefore, important to observe both the diversity and the species that make up this community in order to estimate its stability.

RECOMMENDATIONS FOR COASTAL PROTECTION AT THE INDIANA DUNES NATIONAL LAKESHORE

Introduction

As a result of this investigation, it is strongly recommended that natural alternatives to coastal erosion control should be used for coastal protection of the Indiana Dunes National Lakeshore. The other acceptable alternative to this recommendation is to allow the coastal area to maintain itself in a natural state. This latter alternative may not be feasible at this time because of the proximity of private homes to the rapidly receding coastline. Therefore, specific recommendations, which center on natural erosion control alternatives, have been included in this last section.

Beach Nourishment Alternative

There are four primary recommendations for future beach nourishment projects:

1. Complete beach nourishment should be undertaken so that end failure will not compromise the fill performance.

2. Nourishment sediment characteristics should be carefully determined to ensure maximum stability of the fill.

3. Nourishment fill should be placed on the beach as a wetted slurry to avoid cohesion and intergrain stability problems resulting from wet hauled sediment placement.

4. The foreslope design of the nourishment structure should be compatible with natural beach and berm slope characteristics.

Each of these specific recommendations has been supported with detailed discussion in previous sections of this report. Therefore the following comments are intended to briefly summarize that discussion.

One of the primary areas of degradation in the current beach nourishment section is the updrift limit of the fill. This abrupt termination of the fill is subject to erosion from both the front and the side. Thus failure rate is accentuated at this point and overall performance of the fill is degraded by lateral erosion of the structure.

Nourishment sediment characteristics should be selected with a greater concern for stability of the fill. Conventional selection criteria are based on incipient motion to size relationships and the sorting contrast between the natural sand and the fill sand. These selection criteria overlook important properties such as, grain-grain interaction, sediment cohesion, and sediment fluidization.

The technique of hauling fill material in and grading it into place has long been recognized as the most ineffective means of placing beach nourishment. Conventional dredging and pumping techniques, which deposit a wetted slurry on the beach, have been used with much higher performance success.

The steep foreslope which was left at the lakeward intercept of the current beach nourishment project is totally inadequate for

reasonable fill performance. This type of design creates an initial instability in the fill which acts to accelerate normal degradation. The design of a proper foreslope is beyond the scope of this investigation, however, performance records of other beach nourishment projects indicate that lower foreslope angles are desirable.

Coastal Dune Degradation

There are three primary recommendations for future management and planning of the coastal dune system:

1. When artificial planting is deemed necessary, a combination of several indigenous flora types should be used.

2. Bluff stabilization should be allowed to occur naturally, even though recession of the bluff will continue.

3. Human access to the dunes and beach should be limited to forested areas or those areas totally devoid of vegetation.

This set of recommendations resulted from careful consideration of vegetation distribution and environmental tolerances, sediment characteristics within the dunes, and the recognized desirability of human interaction with the natural environment.

In order to increase the likelihood of successful artificial planting, certain characteristics of plant establishment should be observed. Varying climatic conditions may result in an unfavorable environment for all flora types at some time during a growing season.

In an area of active sand transport it is desirable to use one plant type which is well adapted to rapid burial and capable of

capturing sand combined with another plant type which has substrate holding roots. Combining plant types, with complimentary survival traits, increases the likelihood that an area will remain undisturbed. For example, *Ammophila*, capable of capturing moving sand, is useful in stabilizing high energy areas, and because of their extensive root systems, *Calamovilfa* and *Elymus* are efficient sand holders.

By combining *Ammophila* and *Calamovilfa* in more exposed areas or *Ammophila* and *Elymus* in more protected regions, the possibility of holding the area is enhanced. Since climatic conditions have already selected those species best adapted to the environment, the use of naturally occurring vegetation is recommended for artificial planting.

Desiccation is one of the major causes of mortality in young plants. Development of a nodal root system, critical for the success of plant establishment, requires occasional moisture in the upper few inches of sand. Therefore, during the first week, periodic watering of artificially planted areas is suggested, especially if natural moisture input is infrequent. Small amounts of fertilizer may be added at planting and at periodic intervals to enhance establishment and encourage denser growth.

Bluff stabilization is best accomplished through natural means unless physical processes such as groundwater seepage or run-off require special attention. Bluff recession will continue until the slope reaches a natural angle of repose, then natural vegetation, best suited to the environment, will establish itself. Artificial planting may be utilized in critical situations, but the likelihood of success is low.

Human access routes should be limited to forested zones or areas where vegetation is absent. The presence of dense forest diminishes wind velocity and thus decreases the potential for aeolian erosion. Furthermore, high transpiration rates of mesophyte trees and canopy shading maintain a relatively high moisture content in the soil. Because moist sand is relatively more difficult to disturb, the threat of sand removal is lessened. Bare sand areas, still highly mobile, are not drastically altered by pedestrian traffic. Disturbed areas are quickly covered on most surfaces with the important exception of bare bluff faces.

The delicate grass ecosystems are susceptible to many forms of erosion and individual plants are easily damaged by human traffic. Drying of the sand surface results from the shallow grass root systems. Evaporation rates are increased by exposure to direct sunlight and high wind velocities. Plants along path edges are especially susceptible to these drying effects. In areas where paths already exist, recolonization should occur naturally if human traffic is eliminated. Some existing paths, leading directly to the beach and lake, may be subject to more severe wind conditions, making artificial planting desirable.

Boardwalks through dune forest areas and staircases leading down bluff slopes are recommended for human trafficing. Special effort should be made to establish a strong stand of vegetation around the top of staircases to attenuate run-off erosion and slumping. Boardwalks should not be necessary on bare sand environments.

The preceding recommendations may help in the formulation of future plans for the National Lakeshore development. It would be desirable to pursue some of these recommendations further with respect to specific areas of applicability. This pursuit should be considered for the future, as human use of the Lakeshore increases.

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INTRODUCTION

Appendix A consists of a listing of the major plants, identified in this study, which characterize the different vegetation zonations that exist in the study area. The genus name is followed by either one or several species names that were identified in these areas. The common name of the plant or plant family is then given, followed by the seasonal characteristic of the plant (i.e. Annual, biennial, perennial). Important vegetative information is listed, indicating where it is most likely to be found or where it is best adapted to exist, as well as special vegetative characteristics that allow it to adapt to the conditions present.

Appendix B is an additional listing of plants which have been identified by other investigators in areas similar to our study area. Even though these were not identified during this study, it is quite possible that they do exist along these dune regions.

APPENDIX A

Amaranthus albus - (Pigweed) (Tumble weed) Annual, waste ground, rolls over ground, reproduces by seed.

Ambrosia sp.- (Ragweed) Annual, old pastures, wastelands, roadsides, vacant lots, stubble fields, sea-beaches; reproduces by seed.

Amelanchier arborea - (Downy serviceberry) Perennial, cottonwood associate, black oak associate; streambanks, fencerows.

Ammophila breviligulata - (Marram grass) Perennial, pioneer plant; embryonic dunes, blowouts, foredunes, dune cliffs, eroding windward slopes, steep lee slopes, blowout summits,
Dune captor: Excellent vertical growth character, young shoots have hard pointed tips to grow through sand easily; extensive rhizome propagation radially.
Dune holder: Capable of indefinite aerial expansion; dense social growth, difficult for wind to start process of sand removal; reinforces foredune sand with stolons, roots, and shoots; flowering and vigor decreases after stabilization is complete, renewed sand deposition revives new vitality.

Andropogon scoparius - (Little bluestem) Perennial, pioneer plant, prairie associate, undercover type for black oak; sunny south slope dominant; areas of some sand deposition; usually replaces Marram grass; foredune, blowout; slow germination prevents invasion of new dune area; good indicator of slowed deposition; enlarges dune area without rhizome propagation but by social habit; capable of internodal elongation; shade intolerant.

Anemone virginiana - (Thimbleweed) Perennial, true prairie associate; woods, meadows.

Artemisia sp. - (Wormwood) Biennial, Dune grass associate, upper beach plant (normally characteristic species); foredune, naked places, new plant in windsweeps, blowout, direct sun; most dune societies inland.

Asclepias cornuti - (Milkweed) Perennial, secondary plant, bunch grass associate, prairie associate; embryonic dunes, foredune, lee slope capture and climax; quickly follows Marram grass in succession.

Cakile edentula - (Sea rocket) (Tumbleweed) Annual, pioneer plant; middle beach, foredune, windward slopes of active dunes, among driftwood on beach, blowouts; succulent plant; xerophytic adaptations, thick fleshy leaves, waxy cover, long roots; holds sand, adds organic matter, reduces wind speed, increases humidity, provides shade, reduces soil temperature.

Calamagrostis canadensis - (Reedgrass) Perennial, secondary plant; most persistant dune holder; difficult to dislodge; not a good dune builder; chief character on active dunes, embryonic dunes, leeward side capture; leaves, stems, and roots stiff and wiry; mechanically stable against wind; roots form dense rhizomatous mats making sand removal difficult; controls surface runoff; quickly follows Marram grass in succession.

Calamovilfa longifolia - (Prairie sandreed) Perennial, pioneer plant, common associate of Marram grass; dominant dune builder in slow sand deposition; foredune; re-establishes disturbed sand in sunny areas; persists on eroding dunes, binding residual knobs or "turret dunes"; dense rh zomatous mats control surface runoff.

Carduus nutans - (Thistle) Biennial, sandy fields near coast, waste places, open woods.

Carex sp.- (Sedge) Perennial, black oak associate; rhizomatous in large colonies; marshes, swamps, rich meadows, shores.

Ceanothus americanus - (New Jersey Tea) Perennial, shrub; black oak undercover.

Cenchrus tribuloides - (Sandbur) Annual, dry sandy soil, recently disturbed areas, open ground, roadsides, waste places, fields.

Cirsium (pitcheri, vulgare) (Thistle) Perennial, foredune, blowout, meadow, waste places; extensively creeping horizontal roots; a small bit of root stalk can start a new plant.

Corispermum hyssopifolium - (Bugseed) Annual, goosefoot family; middle beach, upper beach, more prevalent on active dune and foredune than beach; usually deeper wind sweeps and blowouts; rapid seed germination; xerophytic adaptations; succulent plant; no value in dune capture.

Cornus (alterniflora, florida, stolonifera) - (Dogwood) Perennial secondary plant, black oak associate, dune builders; climax on lee slopes; may create extensive thickets; abundant about margins of miniature forests; less fit as xerophyte.

Cycloloma atriplicifolia - (Tumble weed) Annual, pioneer plant; upper beach, foredune; thrives on nutrients from buried organic matter; provides no protection to dune.

Daucus carota - (Queen-Annes-Lace) Biennial, dry fields, old meadows, wasteplaces, pastures.

<u>Elymus canadensis</u> - (Canada wild-rye) Perennial, pioneer plant, true prairie associate; open places, along with Marram grass; rare on beaches; windsweeps, abundant about the margins of miniature forests; enlarges dune areas without extensive rhizome propagation but by seed development; not effective by itself; has been known to stand up at public beaches despite human pressure.

<u>Equisetum hyemale</u> - (Scouring rush) Perennial, secondary plant, sometimes pioneer, bunchgrass associate, prairie associate; quickly follows Marram grass in succession; leeward side capture; foredunes, sand or clay shores

<u>Euphorbia</u> (<u>carollata</u>, <u>polygonifolia</u>) - (Spurge) Annual upper beach, middle beach, naked places, blowouts, xerophytic adaptations; succulent plant; prostrate habit; copious supply of latex from broken stem.

<u>Euonymus atropurpurea</u> - (Burning-bush) Perennial, rich moist woods, ravines, stream bottoms.

<u>Hamamelis virginiana</u> - (Witch hazel) Perennial, black oak associate; common and characteristic about the margins of miniature forests; moist soils near streams, thicket, clearings.

<u>Helianthus divaricatus</u> - (Sunflower) Annual, black oak associates; weed of waste places, plains, cultivated fields, fence rows, roadsides.

<u>Hepatica</u> (<u>americana</u>, <u>triloba</u>) - (Round lobed Hepatica) Woodlands; grows well in shaded areas, sometimes on sunny hillsides.

<u>Juniperus virginiana</u> - (Juniper) Perennial
Secondary plant; along whole coast, pine bottom vegetation; dry soils, exposed rocky or sandy places.

<u>Liatris scariosa</u> (Large button - snakeroot)
Black oak associate; dry woods, clearings; found with golden rod and asters; resembles ironweed.

<u>Lonicera sp</u>.- (Honeysuckle) Perennial
Shrub; fencerows, thickets, borders of woods, roadsides.

<u>Malus sp</u>.- (Common apple) Perennial
Old fields, along roadsides, remote forested areas.

<u>Marrubium vulgare</u> - (Horehound) Perennial
Waste places, old pastures, sparsely wooded areas.

<u>Miscanthus sinensis</u> - (Grass) Perennial
Untended ground

Morus alba - (White mulberry) Perennial
Rich moist sites.

Muhlenbergia frondosa - (Grass)
Low woods, alluvial banks, moist ground; rhizomatous nature.

Oenothera rhombipetala - (Evening primrose) Biennial
Prairie associate, black oak associate; foredune blowout.

Opuntia - (rafinesquii) - (Prickly pear cactus) Perennial
Prairie associate, old black oak dunes.

Panicum virgatum - (Switchgrass) Perennial
Prairie associate, cottonwood associate, black oak associate; sand flats.

Parthenocissus quinquefolia - (Virginia creeper)
Black oak associate, cottonwood associate; woods, thickets; deciduous creeper, adhesive disks at the end of the tendrils.

Phlox sp. - (Phlox)
Upper beach; open places, base of dune, thickets, sandhills, prairies.

Pinus (banksiana, resinosa, strobus) - (Pines) Perennial
Secondary plant; occasional tree in basswood dunes; foredunes; first comers may be within a few years of the age of the dune surface; cannot survive burial, succeeded by black oak forest usually.

Populus (balsamifera, deltoides, grandidentata, monilifera) - (Cottonwood) Perennial
Significant dune formers; little vegetative propagation; many seeds germinate in protected depressions on upper beach and blowouts that reach down to water level; great vertical growth capability; dunes formed are subject to erosion because the dune shape formed is not compatible with wind action.

P. balsamifera - Tertiary plant; upper beach; young grow rapidly; groups of trees retard wind; form highest dunes parallel to shorelines; can reveal former presence of dune depressions concealed by present topography by sprouting at water level and growing up with the dune until found on dune crest.

P. deltoides - Pioneer plant; top of foredune; thrives under sand burial; dominates summit of barren blowout dunes, arise in moist sand at water level and grows until found on the dune crest.

P. grandidentata - Pioneer of burned over areas in abandoned fields; prefers richer and moister soils than others; propagates freely by root suckers.

P. monilifera - Common on basswood dunes; upper beach, blowouts; young grow rapidly; groups of trees retard wind; form highest dunes which are parallel to shoreline.

Prunus (pensylvanica, pumila, serotina, virginiana) - (Cherry) Perennial
Black oak associates
P. pumila - secondary plant, dune builder; upper beach, foredune, climax on lee slopes; social habits; roots grow into buried organic layers; almost as important as grass as a dune builder; dune is high and steep because of pronounced vertical growth and slight radial propagation.

P.virginiana - Dune builder; climax on lee slopes; found around margins of miniature forests; greater abundance when forest cover present.

Ptelea trifoliata - (Hoptree) Perennial
Common and characteristic about margins of miniature forests; dry sandy or rocky situations, river valleys; often an "understory" tree.

Pteridium aquilinum - (Western bracken fern)
Black oak associate; open woods, rock slides, slopes in damp or dry places.

Quercus (coccinea, rubra, velutina) - (Oak) Perennial
Q. coccinea - Occasional tree of basswood dune; cannot survive burial.
Q. rubra - Major tree of oak forests; restricted to lee slopes; protected pockets of young dunes.
Q. velutina - (Black oak) Tertiary plant; prevails as major tree on Indiana dunes; richer soil than just bare sand.

Rhus (copallina, spp.) (Sumac) Perennial
Shrubs, climbing vines, deciduous creepers; black oak associates, basswood - maple habit, cottonwood associates; common and characteristic about the margins of miniature forests.

Robinia pseudoacacia - (Locust tree) Perennial
Prefers deep rich soil of moist bottom lands, but hardy on poor dry sites; sterile ridges; fast growing.

Rosa (virginiana, nitida, spp.) Perennial
Secondary plant, black oak associate; widespread with prairie grass and thickets; common low shrubs around margins of miniature dunes; some have rhizomes.

Rubus sp. - (Blackberry) Perennials
Thickets, bramble patches, and sand dune tangles.

Salix (discolor, interior, nigra, spp.) - (Willow) Perennial
Secondary plants; upper beach, blowouts that have reached down to water level; almost as important as grass as a dune builder; vegetative increase same as grass; buried stems send out roots;

vertical elongation good; xerophytic adaptations, thick cuticle on leaves; social habit; thrive and increase on leeward slopes (protected); common until real forest vegetation is established; root exposure generally not harmful.

Sassafras albidum - (Sassafras) Perennial
Black oak associate, abundant tree in basswood dune; likes richer soil than pure sand; near interdunal ponds.

Setaria lutescens - (Yellow foxtail) Annual
Open ground, forebeach, cultivated fields.

Smilax (hispida, spp.) - (Greenbriers) Perennial
Black oak associate, basswood - maple habit; secondary openings on old dunes; low moist thickets, woodlands, along streambanks; impenetrable tangle of woody and herbaceous vines.

Solidago spp. - (Golden rod) Perennial
Black oak associate, dune grass associate; embryonic dune, new plant in windsweeps, blowouts.

Tilia americana - (Basswood, American linden) Perennial
Basswood dune associate; dominant tree of first forest and old lee slopes; restricted to lee slopes and protected pockets of young dunes; rich sandy soil, bare, loose, shifting; steep slopes near shore; germinates near water table and in favorable seed beds shaded on lee slopes of old lee dunes; growth thick, thrives with sand burial.

Typha sp. - (Cattail) Perennial
Chiefly in water; marshes, waste wet areas, ditches; creeping rhizomes.

Verbascum thapsus - (Common mullein) Biennial
Waste places, old fields, roadsides, pastures, fencerows, dry gravely and stony soils.

Verbena stricta - (Hoary vervain) Perennial
Hot, dry open places, damp places, prairies, barrenlands, pastures, old fields.

Viburnum acerifolium - (Maple - leaved viburnum) Perennial
Black oak associate; large shrub; moist to dry and often rocky woods; banks of streams, borders of swamps, bottomlands.

Vitis (riparia, cordifolia) - (Grape) Perennial
Secondary plants, one of the first perennials in foredune marram grass association, black oak associate, basswood-maple associate; dry beach, naked dunes, riverbanks, thickets, climbing vine in dead trees, remains in established forests; grows rapidly on lee slopes, protected not on crest; hold sand, reduce wind, adds organic matter.

<u>Xanthium</u> <u>strumarium</u> - (Cocklebur) Annual
Upper beach around driftwood; rich soil, cultivated fields, abandoned land, poor pastures, bottomlands, waste places, vacant lots; holds sand, adds organic matter, reduces windspeed, increases humidity, provides shade, reduce soil temperature locally.

<u>Yucca</u> <u>filamentosa</u> - (Bear-grass) Perennial
Dry sandy open woods, clearings, old fields.

APPENDIX B

Abies balsamea - (Pine balsam) Perennial
Tertiary plant; basswood associate, coniferous forest.

Acer (rubrum, saccharinum) - (maple) Perennial
Black oak associate, basswood associate.

Agropyrum sp. - (Grass) Perennial
Upper beach; replaces Ammophila in northern Lake Michigan dunes; embryonic dunes; creates dune expanses; capable of indefinite aerial expansion.

Ampelopsis quinquefolia - (Vine) Perennial
Basswood-maple associate, climbing vine, moist wood and thickets, swamps, stream bottoms.

Arabis lyrata - (Rock-cress)
Black oak associate

Arctostaphylos uva-ursi - (Bearberry) Perennial
Secondary plant; black oak associate; pine bottom vegetation; moderate dune former; procumbent creeper.

Arisaema triphyllum - (Jack-in-the-pulpit)
Forest herb; maple forest; rich moist woods, thickets.

Aster (laevis, macrophyllus, linariifolius, azureus) - (Aster)
Coniferous forest herb; borders of woods, thickets, dry fields.

Betula papyrifera - (Birch family) Perennial
Occasional tree in basswood dunes.

Campanula rotundifolia - (Bellflower)
Fossil beach; terrace of embryonic heath.

Carya (cordiformis, ovata) - (Hickory) Perennial
Black oak associate.

Celastrus scandens - (Fruiting bittersweet)
Basswood-maple associate; deciduous creeper, climbing vine.

Celtis (occidentalis, pumila) - (Hackberry)
Black oak associate; shrub; common about margins of miniature forests.

Cephalanthus occidentalis - (Buttonbush) Perennial
Secondary plant; embryonic dune, swamps, streambanks; slowly accumulate sand and creates dunes.

Cnicus Pitcheri - (Thistle) Biennial
Upper beach; dune complex, blowouts; xerophytic adaptation, protective wooly hairs.

Coreopsis tripteris - (Tickseeds)
Black oak associate; moist open woods, thickets.

Cyperus schweinitzii - (Yellow nutsedge) Perennial
Bunchgrass associate; foredune, cultivated fields, rich or sandy soils; often limited to low, poorly drained areas in fields.

Diervilla (lonicera, trifida) (Bush-Honeysuckle) Perennial
Black oak associate; deciduous creeper; dry rocky, open woodlands, thickets.

Epifagus virginiana - (Beach-drop)
Woods; shade of beach trees; maple forest.

Fagus (ferruginea, grandifolia) - (Hemlock) Perennial
Beech-birch-maple associate; deep fertile and well drained soils; roots sprout vigorously

Festuca octoflora - (Sixweek Fescue) Annual
Very open places, waste ground, dry thin soils.

Fragaria virginiana - (Wild strawberry)
Pine bottom associate; open woods, fields, grassy slopes.

Fraxinus Americana - (white ash) Perennial
Black oak associate; occasional basswood dune tree; deep, rich, well drained to moist soils; bottomlands, ascends slope where soil is not too dry and stony.

Gaultheria procumbens - (Teaberry)
North Lake Michigan; black oak associate; evergreen with creeping underground stems; sandy or rocky woods and clearings.

Gaylussacia baccota - (Black Huckleberry)
Black oak associate; dry sandy or rocky woods, bags.

Helianthemum canadense - (Frostweed)
Black oak associate; rocky open woods, sandy barrens.

Hudsonia tomentosa - (Beach-heather)
Fossil beaches; dry sand; sand dunes; clumps of densely tufted growth.

Hypericum kalmianum - (Kalm St. Johns-wort)
Sandy or rocky open woods and clearings; undrained swamp margins.

Juglans cinerea - (Butternut, walnut)
Occasional tree in basswood dunes; rich moist soil, bottomlands, follows streams.

Juncus Balticus littoralis - (Rush) Perennial
Pioneer; miniature dune former; blowouts; dense rhizomatous mats on low topographic relief; controls surface run-off.

Koeleria cristata - (Junegrass) Perennial
Prairies, open woods, glades.

Krigia virginica - (Dwarf dandelion)
Dry open woods, fields roadsides.

Lathyrus maritimus - (Beach pea) Perennial
Pioneer plant; upper beach on clay bluffs, extensive rhizome propagation.

Lespedeza capita - (Bush-clover)
Black oak associate.

Linaria canadensis - (Blue toadflax) Perennial
Very open places; dry sandy soil, clayey fields, roadsides.

Lithospermum (craceum, hirtum)- Perennial
Prairie associate, black oak associate, dune grass associate; rejuvenated dunes, foredunes, blowouts, limey soil; grain fields, meadows, waste places.

Lupinus perennis - (Wild lupine)
Black oak associate; dry open woods, thickets, sandhills.

Monarda (fistulosa, punctata) - (Horsemint)
Prairie associate, foredune associate; blowout, fencerows, waste places, open sandy woods and fields.

Ostrya virginica (American hop hornbeam)
Basswood dune associate; common small understory tree; dry, gravelly or rocky slopes; ridges, bottomlands.

Phalaris arundinacea - (Reed canary grass) Perennial
Pioneer plant; along shores, meadows; has rhizomes, helps control stream bank erosion.

Poa compressa - (Canada bluegrass) Perennial
Northern Lake Michigan; open ground, fields, prairie meadows, dry woods; forms loose soil; has rhizomes.

Polygonum amphibium - (Water smartweed) Perennial
Secondary plant; meadows, swamps, shores, ditches; has rhizomes, traps sand.

Polygonum Hartwrightii - (Knotweed) Perennial
Secondary plant; builds low dunes; swampy depressions.

Potentilla Anserma - (Silverweed) Perennial
Pioneer plant; low dune builder; secondary embryonic plant; swampy depressions; sandy shores, banks; has stolons.

Pyrola sp.- (Wintergreen)
Dry or moist woods, thicket, and bogs.

Scirpus (acutus, americanus) - (Bulrush) Perennial
Pioneer plant; woody shrub; marshes and on shores; has rhizomes.

Shepherdia canadensis - (Canada buffaloberry)
Open places in coniferous forests; sandy or rocky woods, along streams.

Smilacina racemosa - (False spikenard, False Solomons - seal) Perennial
Black oak associate; rocky wooded slopes.

Smilacina stellata - (Sun -flowered solomon's seal) Perennial
Black oak associate, coniferous forest associate; deciduous creeper, moist wooded slopes, shores, bluffs, meadows; has rhizomes and stolons.

Sorghastrum nutans - (Indian grass) Perennial
Black oak associate; upland prairies, glades, open woods; has short rhizomes.

Stipa spartea - (Porcupine-grass) Perennial
Prairie associates; roadsides, rocky slopes.

Tephrosia virginiana - (Goats-rue)
Black oak associate; dry open woods, thickets, fields of sandy soils.

Thuja occidentalis (American arbor-vitae)
Basswood dune associate; typical of swampy areas.

Tradescantia (ohioensis, virginica) - (Spiderwort) Perennial
Dry woods, open places.

Trillium grandiflorum - (Large-flowered Trillium)
Rich moist woods, thickets, forest herb.

Tsuga canadensis - (Common hemlock tree) Perennial
Occasional basswood dune associates; characteristic of mesophytic forest, cool moist situations, along streams, borders swamps and bogs, on steep northward facing slopes.

Ulmus fulva - (Slippery elm) Perennial
Occasional basswood dune associate; wide lateral roots.

Vaccinium (angustifolium, canadensis, vacillans) - (Blueberry)
Black oak associate; woods, clearings, sandy areas.